Safety prevention approaches and standards to mitigate dust and gas explosions

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by

Hulisani Muvhango (200911125)

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SUPERVISOR: Prof. A.L Marnewick

CO-SUPERVISOR: Dr. K. Olatayo

Declaration

I, *Hulisani Henry Muvhango* hereby declare that this minor dissertation, Safety prevention approaches and standards to mitigate dust and gas explosions, submitted for the Master's degree in engineering management at the University of Johannesburg, is solely my work and has not been submitted anywhere else for academic recognition either by me or by any other person.

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This study is wholly dedicated to my late beloved son Thendo Odirile Muvhango – your short-lived life will be the seed for our future successes.

Abstract

Dust and gas explosions are characterized by damage to property and fatal consequences related to their occurrence. Despite laws, regulations, and standards to prevent and mitigate explosions, dust and explosions are a recurring event in South African industries. This study aimed at identifying if a gap existed between South African local regulations and standards to prevent and mitigate industrial explosions. A comparative literature review was done to identify the international best practice regulations and standards. Risk reduction measures presented in the hierarchy of loss prevention control such as inherent safety, passive engineered safety, active engineered safety, and procedural safety were reviewed to incorporate process safety human factor and company culture as additional contributing factors to dust and gas explosions. A survey questionnaire was structured using the principles from the hierarchy of loss prevention control and recommended local and international regulations and standards. The survey was distributed to professionals and experts in the edible oil industry.

The responses received show that three knowledge gaps exist within the industry professionals and experts. The knowledge gaps are within the following principles of the hierarchy of loss prevention control: (i) Inherent safety - respondents showed a lack of awareness and utilization of area classification information. The lack of exposure can be attributed to manufacturing companies outsourcing the design of processes and plants and area classifications to engineering design and consultancy companies. (ii) Engineered safety - respondents lack awareness of the significance of passive barriers that are within their systems. This can result in poor decision-making when encountering an emergency- as the knowledge of the safer areas of the plants or site is poor within respondents. (iii) Process safety management - inconsistent responses were noted with 9 respondents (53%) showing confident awareness but 11 respondents (65%) claim to utilize the principles. The 2 respondents showed utilization of permit to work issuance procedures but lack awareness of legal liability compliance.

This knowledge gap within industry professionals can be detrimental – as accidents can occur in areas that required re-zoning (area classification) and segregation when performing site upgrades.

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List of Acronyms

ALARP:	As Low As Reasonably Possible
API:	American Petroleum Institute
AS:	Australia Standards
ASTM:	American Society for Testing and Materials
ATEX:	Atmosphere Explosibles
AU:	Australian
CE:	Conformitè Europëenne
CEN:	European Committee for Standardization
CENELEC:	European Committee for Electrotechnical Standardization
COIDA:	Compensation for Occupational Injuries and Diseases Act
CSB:	Chemical and Hazard Safety Board
DDT:	Deflagration-to-Detonation Transition
EC:	European Council
EIR:	Electrical Installation Regulations
EMR:	Electrical Machinery Regulations
EPCM:	Engineering Procurement Consulting Management
GCC:	Government Certificate of Competency
GMR:	General Machinery Regulations
H&S:	Health & Safety

HAZOP:	Hazard and Operability Study
IEC:	International Electrotechnical Commission
IEEE:	Institute of Electrical and Electronics Engineers
ISO:	International Organization for Standardization
KPI:	Key Performance Indicators
LFL:	Lower Flammable Limit
MEC:	Minimum Explosible Concentration
NFPA:	National Fire Protection Association
NZ:	New Zealand
NZS:	New Zealand Standards
PPE:	Personal Protective Equipment
PSM:	Process Safety Management
R:	Regulation
SA:	South Africa
SABS:	South African Bureau of Standards
SA-DOL:	South African Department of Labour
SADCSTAN:	Southern African Development Community Cooperation in Standardization
SANS:	South African National Standards
SOP:	Standard Operating Procedures
UFL:	Upper Flammable Limit
UN/ECE:	United Nations Economic Commission for Europe
UPS:	Uninterrupted Power Supply
WSSN:	World Standards Services Network

1 Chapter 1

1.1 Introduction

Industrial dust and gases are common by-products and solvents utilized in the manufacturing of high-end products. The poor management and handling of these clouds of dust and gasses can result in explosions causing fatalities in the workplace [1], [2]. Employee safety in all industries is an essential aspect of the organizations' human resources. The human resources acquired by an organization are crucial in the strategic execution of the organization's profit-driven strategy [3]. Employees in the manufacturing, chemical, petrochemical, and mining industries are continuously exposed to different types of hazards. The hazards presented by the process itself – if operated incorrectly it can cause harm to the organization and its community [3]. The occurrence of an accident can result in a guilty violation of South African labor laws. If an organization violates South African labor law, it can result in civil claims (in case of death), medical claims (in case of injury) which can consequently lead to loss of productivity, low morale, and efficiency [3]. Although organizations implement principles of the hierarchy of loss prevention control such as - hazard elimination, hazard substitution, engineered safety approach, procedural and administrative, as well as safety standards and regulations outlining how work is to be executed – accidents are impossible to fully eradicate in totality. Hence, Van Den Honert [3], found that human behavior is the biggest concerning variable in the accidents reported by organizations as humans are subject to work-place stress thus resulting in 60 to 80 percent of all workplace accidents [3]. However, caution should be taken to highlight that both employer and employee fall within the category of human behavior [3]. Organizations are continuously tasked to implement and maintain occupational health and safety regulations and standards to mitigate the risks to which their employees are exposed [3]. Van Den Honert [3], notes that organizations are required to decide whether a risk is acceptable or whether further prevention approaches are required to mitigate the hazard. However, as much as each process consists of various safety complexities, human behavior continues to be a common cause of most accidents. This occurs when risks cannot be mitigated to As-Low-As-Reasonably-Possible (ALARP), then employers (organization) rely on the expertise of a Health & Safety (H&S) Officer to suggest additional recommendations and accept the risk is ALARP [3].

South African Department of Labour (DOL)

The South African department of labor (SA DOL), is tasked with the mission to regulate the South African labor market, through the implementation of appropriate legislation and regulations, inspections, and enforcing of compliance, by also promoting equity, social and income protection, and protection of human rights [4], [5]. SA DOL develops basic working conditions, occupational health, and safety regulations. It further handles the deployment of occupational health and safety standards, which includes the Compensation for Occupational Injuries and Diseases Act No 130 of 1993 (COIDA). It assists with compensation to employees who are medically declared disabled as a result of an occupational injury or diseases contracted in the course of employment, or for death resulting from the sustained injuries or diseases [6]. The compensation fund is obliged to report on the annual statistics of occupational injuries and fatalities in the South African workplace [5].

South African Occupational Statistics

Occupational fatalities and injuries are common within workplaces that do not have occupational health and safety systems in place. Moreover, organizations that only perform the bare minimum of standards and regulations implementation continuously place employees' lives at risk. During the year 2018, approximately 184,424 organizations were inspected [5]. It was found that 32,289 organizations were not compliant with SA labor laws [5]. During the same year, a total of 144,540 non-fatal workplace injuries and 348 fatal workplace accidents were reported [5]. **Table 1**, below represents the fatal and non-fatal accidents and incidents which occurred within the South African workplace within 4 years between 2014 and 2018 [5]. During this period approximately 500,000 incidents were reported with the compensation fund.

Table 1: South African Occupational injuries 2014 - 2018

Year	Fatal		Non-Fatal		Total
	Number	%	Number	%	
2014	116	0.2%	68,494	99.8%	68,610
2015	90	0.3%	26,628	99.7%	26,718
2016	134	0.4%	37,581	99.6%	37,715
2017	506	0.3%	155,470	99.7%	155,976
2018	348	0.2%	144,540	99.8%	144,888
Total	1,194		432,713		433,907

Industrial Explosions

During the period 2014 to 2018 occupational accidents which resulted in fatalities were approximately 1,194 [5]. Sixteen fatalities resulted from industrial explosions and 13 employees were injured during an explosion accident [7][8][9]–[12]. The SA DOL annual statistic report does not categorize occupational fatalities based on cause hence the data of fatalities from explosions were retrieved from newspaper articles [7][8][9]–[12].

Dust and gas explosions vary due to the physical state of the matter – solid compared to gaseous. Particle size is therefore critical in the prevention of dust explosions [13]. The differences in their explosion regimes are, gas explosion involves a homogeneous system where fuel and air are separated by molecular distances [1], therefore encouraging thorough mixing of the fuel and oxidant without effects of gravity [14]–[16]. However, dust/air mixtures are heavily influenced by gravity and the dust explosion requires a dust/oxidant suspension [17]. Dust is generated in different forms and concentrations in various production environments including grain and food plants; textile manufacturing; electrical power generation; metal production; mining; plastic production and; chemical process industries. Explosible solvents are used in processing plants to extract and in other industries, explosible gases are by-products in the processing plants. These two products if not correctly handled, vented, or stored can result in explosions.

Dust and gas explosions occur suddenly due to a completion of a fire triangle requirements which requires oxygen, a fuel source (dust or gas), and an ignition source for an explosion to occur (fire triangle, **Figure 1a**) [1]. Amyotte and Eckhoff [1] expanded the combustion triangle to include other explosion factors such as mixing and confinement of dust particles, to create the explosion pentagon (**Figure 1b**) [13]. Furthermore, Garcia-Agreda [18], modified the explosion pentagon (explosion pentagon **Figure 1c**) to include the explosion requirements for a hybrid or dust explosion which include combustible fuels (dust or gas) existing simultaneously or independently [18].

Explosions can be categorized into two: primary and secondary explosions. Primary explosions usually occur inside the confines of equipment, i.e. process vessels (tanks, extractors, distillation columns), grinders, mills, and dryers [17], [19]. The explosion is caused by the satisfaction of the explosion triangle/pentagon. A primary explosion is deemed primary if it results in a secondary explosion externally to the process vessels. Secondary explosions are initiated by blast waves arising from primary explosions. According to South African National Standards (SANS) and International Electrotechnical Commission (IEC) standards – all hazardous areas which consist of explosible atmospheres should be zoned according to the relevant standards. Also, areas potentially explosible are required to be independently isolated and ventilated as per International and local regulations and standards [20].

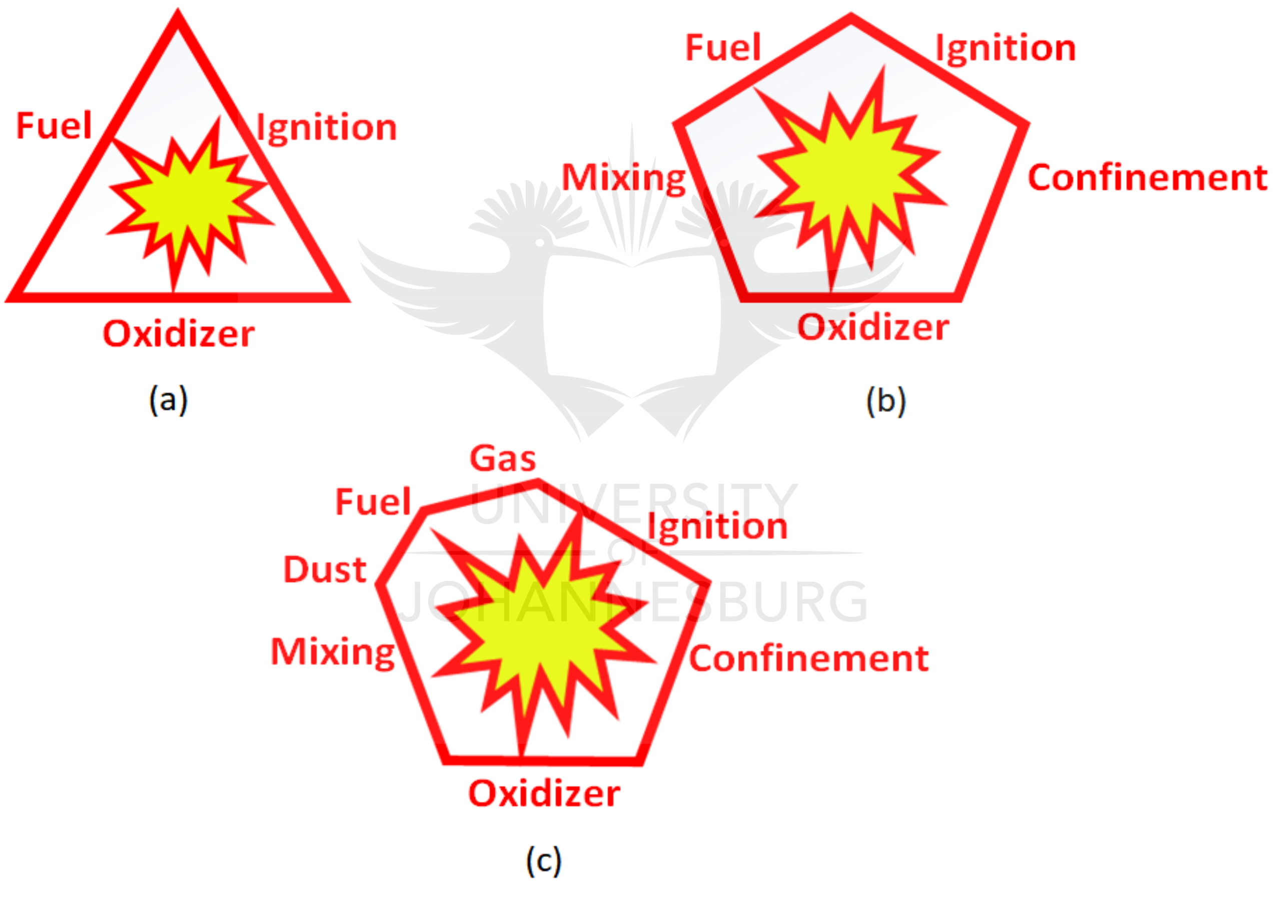

Figure 1: Fire Triangle (a), Explosion Pentagon (b), modified Explosion Pentagon (c) [18]**.**

Local and International Standards

Local South African standards are published by the South African Bureau of Standards (SABS) which was founded in September 1945. SABS is a body established by the Standards Act (Act No. 24 of 1945) to be the national standardization institution. Its mandate is to develop and maintain South African National Standards (SANS) [21]. A "standard" defines the specification required for an equipment or process of equipment manufacture, where a specification further details the in-depth process of manufacture and required components

[21], [22]. SABS is a founding member of the International Organisation for Standardisation (ISO) The South African Bureau of Standards is associated with the following Regional and International Standard Bodies:

International:
IEC - International Electrotechnical Commission
IEEE - Institute of Electrical and Electronics Engineers
ISO - International Organization for Standardization
ASTM - American Society for Testing and Materials
WSSN - World Standards Services Network

Regional:
CEN - European Committee for Standardization
CENELEC - European Committee for Electrotechnical Standardization
UN/ECE - UN Economic Commission for Europe
SADCSTAN - Southern African Development Community Cooperation in Standardization

International Electrotechnical Commission (IEC) 60079 series

This study is focused on the IEC 60079 series which is a series of standards that adopted the European Atmosphere Explosible (ATEX) directives which were published in 1994 and 1999. The two ATEX directives - Directive 94/9/EC and Directive 99/92/EC were published by the European Union Parliament [23]. Directive 94/9/EC deals with equipment and safety protection systems intended for use in explosible atmospheric areas [23]. Explosible areas are categorized as explosible zones in terms of fuel sources (dust or gas). The zones are categorized based on the condition of the explosible atmosphere, where condition refers to the amount of exposure to an explosible fuel source (dust or gas) [14], [23], [24]. Zoning is based on three categories: *continuously present* (zone 0/20); *likely to occur in normal operation occasionally* (zone 1/21) and *not likely to occur in normal operation and for very short durations* (zone 2/22) [14], [23]. The second directive, Directive 99/92/EC recommends the requirements an organization (employer) is required to adopt to prevent uncontrollable release and formation of explosive atmospheres; prevention of ignition and mitigation of explosion effects [23].
Amyotte and Eckhoff. [1] suggest three ways prevent industrial loss: (i) inherent safety, (ii) engineered safety (passive and active), and (iii) procedural safety. Engineered safety involves the installation of safety devices in areas that are prone to incidents. These devices can either suppress the impact of the explosion or can detect the leakage and alert operators of the deviation in the process. Procedural safety is also known as administrative controls, which focuses on implementing safe working procedures, culture and controls to reduce the risk of an explosion. The two abovementioned safety controls are reactive and require additional controls and checks from the process team and health and safety team. Inherent safety seeks to eliminate the hazard or reduce the hazard to its minimal impact, rather than trying to prevent occurrence or mitigating effects. It analyses the properties of a specific material or process to eliminate or reduce the hazard.

1.2 Problem statement

There exists a knowledge gap between international best practices to prevent and mitigate dust and gas explosions and the South African local explosion regulations.

1.3 Research questions

1. What are the prevention and mitigation approaches to dust and gas explosions?
2. What are the gaps that exist between global and local standards on explosion prevention?

1.4 Research objectives

This research seeks to identify and establish the existing gaps between South African local standards and international best practices on the causes, prevention, and mitigation of dust and gas explosions.

1.5 Research rationale

The South African manufacturing and processing sector have experienced several incidents over the past five years (2014 -2019) where lives were lost, and companies had to cease operations due to unanticipated incidents which resulted in losses. South African industry professionals and experts may be able to enforce best practices to create safe working environments.

1.6 Research design

This research was approached through an analytical review of literature on prevention and mitigation approaches and standards. A survey was designed using the principles on the hierarchy of loss prevention. It was distributed to participants to determine the awareness level and utilization rate of best practice explosion prevention approaches and standards by industry professionals responsible for health and safety. This was compared to best practices from the literature review to aid in identifying the knowledge gaps.

The research evidence required is:

- Best practice guidelines for prevention and mitigation and implementation thereof
- Current Local and international standards

1.7 Research layout

Table 2: Research Layout

Chapter	Contents
Chapter 1 – Problem Definition	Definition of the problem and the impact of explosions on the working environment.
Chapter 2 – Literature Review	A detailed review of the causes, prevention, and mitigation of explosions locally and internationally.
Chapter 3 – Research Methodology	Selection of best-suited research method.
Chapter 4 – Data Collection and Analysis	Data analysis of data collection and deduction of results.
Chapter 5 – Conclusion & Recommendations	Conclusion on results and suggestions on the way forward.

1.8 Chapter conclusion

This chapter defined the problem that exists in South Africa, of explosions occurring in the manufacturing and processing industries. These explosions repeatedly occur due to the organizations' lack of implementation of international best practice guidelines for prevention and mitigation. It can be noted that not all processing environments can inherently remove the hazard from the working environment but the hazard can be reduced or minimized to manageable levels. Hence the need for comparison of South African regulations against the international best practices in explosion prevention and mitigation.

2 Chapter 2: Literature review

2.1 Introduction

This chapter explored the literature of prevention and mitigation of dust and gas explosion by exploring the principles of hierarchy of loss prevention control. To decide which approaches were suitable for the prevention of dust and gas explosions, an understanding of the commonalities and dissimilarities between dust and gas explosion was imperative. Moreover, it was imperative to differentiate between primary and secondary explosions as prevention of the primary explosion or reduction of the severity of the primary (lack thereof secondary) explosion is imperative in industrial loss prevention control. By understanding the differences and similarities within explosions; prevention approaches and recommended standards, current challenges in the industry were understood. Therefore, identifying the knowledge gaps between the global and local standards within the South African industrial environment

2.2 Types of Explosion

An explosion caused by dust clouds and gas mixtures exhibits similar ignition and combustion profiles and can be understood by a simple diagram of the fuel-air explosion triangle (**Figure 2**). The fuel-air explosion triangle indicates the necessary conditions for an explosion to occur which are fuel source; oxygen and a source of ignition [16], [25].

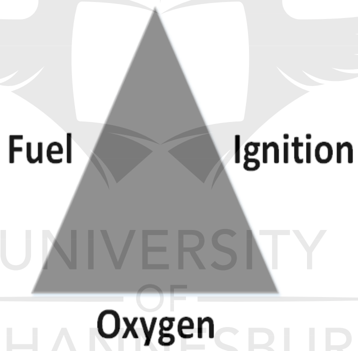

Figure 2: Explosion triangle(CSB, 2006)

When dust or dust-gas (hybrid) mixture explodes it requires that dust is suspended (dispersed) and confined as represented by the explosion pentagon in **Figure 3**. The dust or dust-gas burns rapidly, the fast-burning flame within confinement results in an over-pressurized system thus increasing the rate of the burning dust flame resulting in a dust explosion. Dust clouds even in partial confinement, if ignited can cause an explosion. Dust and gas explosions are catastrophic because if the source area of the explosion is not protected sufficiently it can cascade into multiple explosions [1], [17], [25].

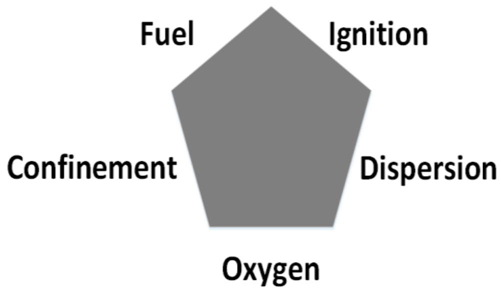

Figure 3: Dust explosion pentagon (CSB, 2006)

Various authors [1], [17], [25], [26] confirmed that dust and gas explosion occur in production environments including grain and food processing plants; textile manufacturing; electrical power generation; metal production; mining; plastic production, and chemical process industries (**Figure 4**). However, explosions in the following industries (food products, chemical processing, primary metals, and lumber and wood products) accounted for nearly 60% of explosions between the period 1985-2005. Moreover; equipment that was most likely to be involved in the explosions are:

1. Grinders and mills which are subjected to friction can result in sparks, dryers that are subjected to smoldering which can result in a fire [1].
2. Extractors and distillation columns that are subjected to overpressure and pump friction result in sparks [16].
3. Cyclones and dust collectors keep dust in suspension generating explosible clouds of dust [16].

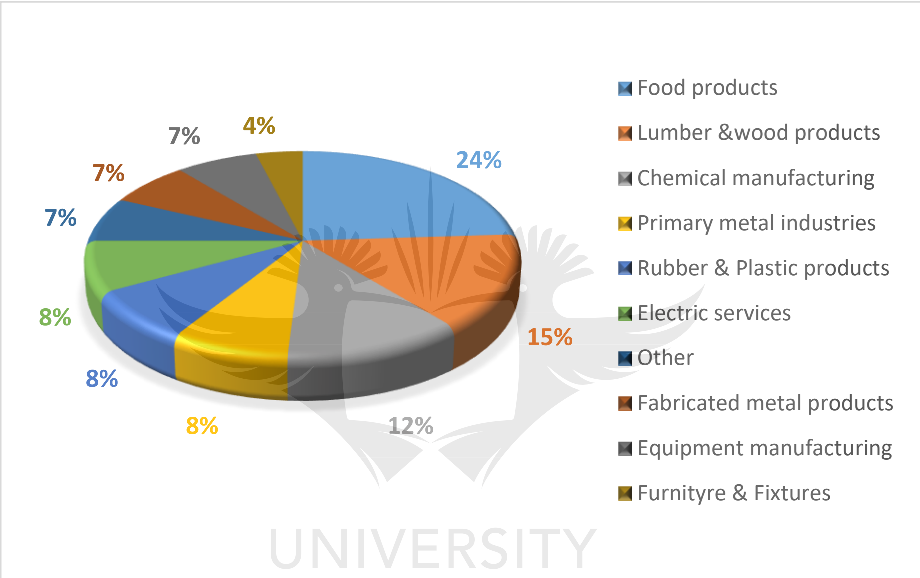

Figure 4: Industrial Explosions (1985 -2005)(CSB, 2006)

Depending on the severity and process equipment layout [15], an initial explosion can cascade into additional explosions [19]. Hence explosions are categorized into two; primary and secondary explosions. A primary explosion is deemed primary if it results in a secondary explosion externally to the process vessels [17]. The external explosion can be caused when dust leaks into the atmosphere and settles on flat surfaces (steel structure beams, cable trays, and other unreachable areas) [25]. When an explosion occurs (**Figure 5**), it disturbs the settled dust creating a pressurized dust cloud wave, initiating a secondary explosion.

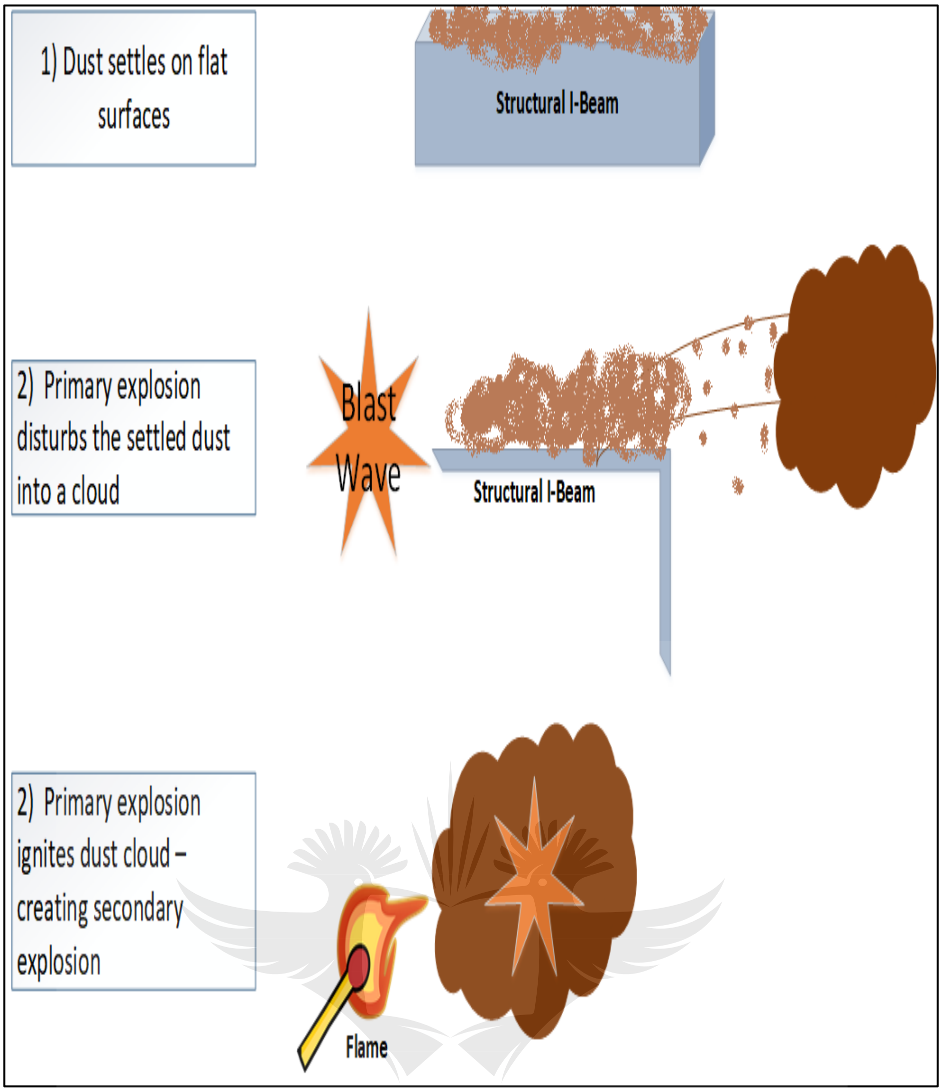

Figure 5: Secondary explosion (CSB, 2006)

2.3 Explosion condition requirements

Dust Explosion

A dust explosion occurs when the minimum explosible concentration (MEC) is met [13], [17], [27]. MEC is defined as the smallest concentration of dust in suspension, that can initiate an explosion [28]. Dust is a different source of fuel, unlike gas, it requires a presence of dust suspension (aeration of dust) and confinement (dust cloud formation) to exist simultaneously to satisfy the necessary conditions for an explosion to occur [17], [29].

Gas Explosion

Gas explosions are defined as rapid reactions where the explosible and oxygen exist within the lower flammable limit (LFL) and upper flammable limit (UFL) [1] and are subject to sources of ignition [19]. The ignition sources generally considered are both thermal or electrostatic sources [26]. However, gas explosions can occur without the presence of an ignition source [16]. Over pressurizing has resulted in a significant amount of gas explosions. It occurs when rapid chemical reaction run(a)way resulting in the production of gases, leading to pressure build-up, thus a delay in condensing vapors, pressure relief venting causes an explosion [30].

Hybrid Explosion

The methane gas/coal-dust hybrid combination is the most renowned hybrid combination which exists in underground coal mining [18], [31]. It consists of an explosible gas and explosible dust, which may be present in the lower flammable limit (LFL) and minimum explosible concentration (MEC) respectively, and present an explosible mixture [1]. **Table 3**, below shows the different explosion conditions required. These explosions are most likely to result in domino effects due to the presence of two different substances (explosion waves agitate settled dust and dust cloud ignites vigorously) [17]. To reduce domino effects which results in catastrophic damages, passive barriers; suppression systems; detectors; venting ducts are some available options to mitigate the impact of an explosion [1], [17], [32].

Table 3: Explosion condition comparison.

Type	**Physical State**	**Explosion Conditions Requirement**						
		Oxygen	**Fuel**	**Ignition**	**Dispersion**	**Confinement**	**MEC**	**LFL**
Dust	Solid	✓	✓	✓	✓	✓	✓	×
Gas	Liquid - Vapour	✓	✓	✓	×	×	×	✓
Hybrid	Liquid-Solid-Vapour	✓	✓	✓	✓	✓	✓	✓

2.4 Prevention and mitigation approaches to dust and gas explosion

When designing a process, which consists of a dust or gas hazard, it is useful to employ a prevention and mitigation framework for making the appropriate decision [17], [18], [33]. Amyotte and Eckhoff [1], state, that industrial loss prevention control is achieved in three ways: (a) inherent safety, (b) engineered safety (active to passive), and (c) procedural safety. In this study, procedural safety is explored further and linked to safety management systems. Moreover, a fourth prevention and mitigation approach explored is the human factor (focusing on the role of management and co-workers) and the company culture. **Figure 6**, illustrates the generally accepted systematic hierarchy of control approach to loss prevention in the industry. When considering this approach, the risk reduction measure (from most effective to least) is inherent, passive engineered, active engineered, and procedural safety management [1]. The current study extended the focus to the impact of human factor and the company culture as the next step to achieving effective loss prevention. **Figure 9**, demonstrates the addition of process safety management system (PSM) and human culture and how it reduces the residual risk through maintaining and updating the live PSM documents that the company should continuously update when process change occurs, improve company culture based on health & safety trends.

2.4.1 Inherent safety approach

The theory of inherent safety was first proposed by Trevor Kletz [1], [15]. He was among the first to recognize that any action is taken towards removing or substituting a hazard (designing to minimize the hazard) resulted in a safer working environment, he focused on topics such as inherent safety, hazard identification, incident investigation, and documenting lessons learned [1], [15]. Inherent safety is defined as a proactive risk management approach in the plant design phase and layout definition, its purpose is to remove the hazard at the source as compared to accepting the hazard and resorting to finding solutions to prevent the occurrence of the hazard [1]. To achieve the greatest impact, inherent safety uses the properties of a material or properties of the process to eliminate or reduce the hazard, in its earliest stage (design stage) of the project life cycle [15]. To fully apply the inherent safety approach in the design phase, guide words are considered, these guidewords assist with determining the appropriate approach for primary explosion prevention, domino effect prevention, and explosion severity mitigation.

Cozzani, Tugnoli, and Salzano [15] identifies, the cause of primary explosions as equipment product inventory and suggests the baseline focus areas using intensification and moderation as a guide word. Inherent safety can be achieved by:

- reduction of inventory in a single equipment
- safer storage conditions, such as underground storage tanks with bonding.
- moderation by using less hazardous conditions, lower process temperatures, and operating pressures.

The four guidewords are intensification/minimization, substitution, moderation/ limitation, and simplification of effects. **Table 4**, shows examples of the application of the four guidewords in dust and gas explosions prevention [1], [15], [17]:

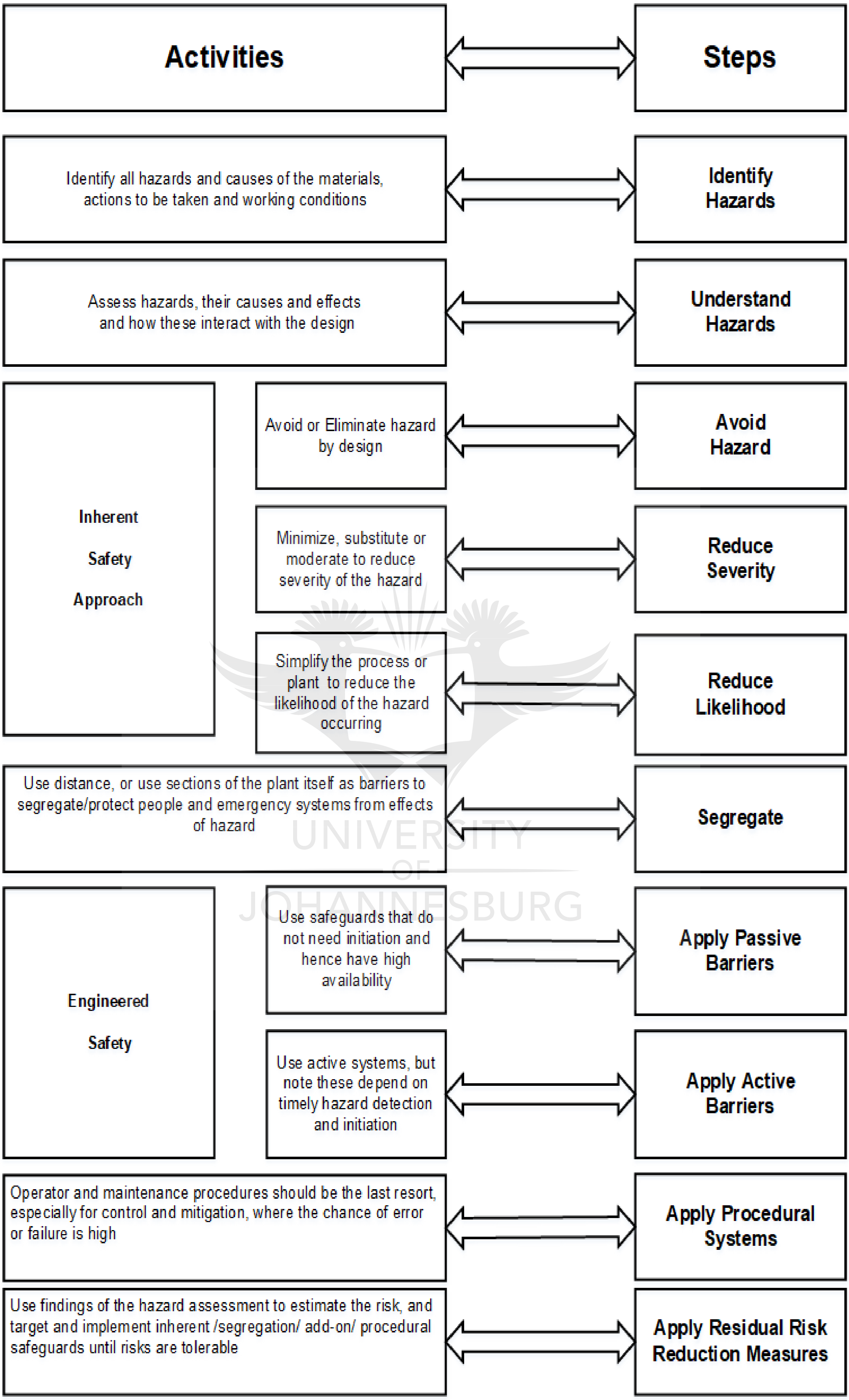

Figure 6: Hierarchy of loss prevention control [1].

Table 4: Inherent safety principles

Principle	Description	Applications
Intensification/ Minimization	- Use small amounts of the hazardous material, when the handling of the material cannot be avoided	- Increase equipment efficiency – whilst reducing operating capacity (work-in-progress)
Substitution	- If possible substitute the hazardous material with one that is less hazardous - Substitute the hazardous process with one that does not involve hazardous material.	-Not feasible if a hazardous substance is desired product.
Moderation /Limitation	- Use hazardous material in their least hazardous forms: - Moderate operating conditions to those that involve less severe operating conditions. -Accepting negative effects can arise but focusing on limiting effects.	-Design process with lower operating conditions (temperature and pressure) -Limiting negative effects to As Low As Reasonably Possible (ALARP)
Simplification	- Design processes and equipment to eliminate opportunities for human errors (automation) or reactive response requirements. - Identifying solutions to eliminate excessive use of engineered safety features and protective devices	- Hazard awareness - Staff training - Procedural safety and upholding of safety culture -Role of management

An inherent safety approach can be conducted in conjunction with a hazard and operability (HAZOP) study. Guidewords are used in HAZOP study to individually assess hazards potentially posed by flow, temperature, pressure, and reactivity [34]. During the layout description phase, focus (key) words that can be used are primary explosion, escalation explosion, and domino explosion [15]. The blast wave regimes of a primary explosion are fundamentally important in developing a process or plant layout which is inherently safe to reduce the severity of a primary explosion [15]. By using the process of the plant itself as barriers to protect people or emergency systems from the hazard [15]. Inherent safety approach is not a standalone approach for prevention and mitigation, it works in correlation with engineered approaches, such as the passive engineered approach being the next prevention approach as it requires little to no activation [1], [13], [17], [26].

2.4.2 Passive engineered safety

Passive engineered devices are systems that are regarded as the last line of defense in an explosion prevention hierarchy of loss prevention control. This is because these devices have no intended function if an explosion doesn't occur [15]. Their function is determined by the physical effect of the explosions, deflagration into detonation (DDT) transition [35], [36]. However, passive engineered safety is considered immediately after the inherent safety approach, as it assists with the process or plant layout description, where segregation and equipment's positioning is decided from an occupational safety; explosion prevention, and mitigation point of view [35].

The design of passive explosion barrier systems has remained similar for several years; these devices are widely used for explosion suppression in the coal mines, with intention of reducing the consequences of an accident [17], [36]. The mechanism used in the underground mines involves the utilization of the kinetic energy in the pressure wave ahead of the explosion, to overturn pre-installed passive barriers dispersing inert material and forming a cloud of non-explosible material (**Figure 7**) [37].

There are two widely used passive barriers in the mining industry and chemical industry and they are stone dust barriers, which have been in use since 1920, and water barriers [38]. Stone dust barriers are deemed not reliable because they cake up (solidifies) easily under humid atmospheres and during the explosion the trajectory of the dispersion of the inert dust is not always guaranteed, thus reducing effectiveness [38]. Water barriers are more superior to stone dust barriers as they are easy to maintain and less expensive, advantages of water barriers are the ability to decrease the concentration of the dust and increases the humidity of the dust [38]. Moreover, the water can disperse into the path of the flame, thus reducing domino effects and escalation [38].

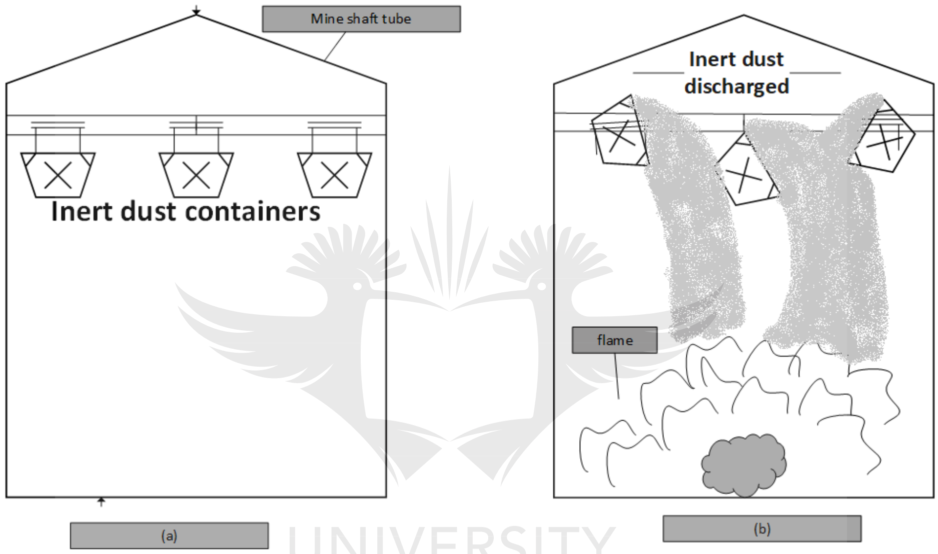

Figure 7: Passive barriers in coal mining shafts. a) Pre-explosion (b) Post explosion (Wang et al., 2017)

Another type of passive device is venting systems, which work passively by relieving explosible pressure clouds that may have accumulated in a specific closed space [39], [40]. In mines and petrochemical industries flames are purposefully vented [40]. If the flue stack or vent line condition is not maintained (cleaned), it can reduce in diameter and impact the venting efficiency leading to an over-pressurized explosion [39], [40]. Nonetheless, new technology has been developed which can be retrofitted in current applications. It is known as a flameless venting flame arrestor; it permits gas flow but prevents flame transmission [41].

Other forms of passive barriers are in a form of wall suppression systems, where a wall is built to create a separation in the zones [19]. A fluid known as aerogel is used to ensure a room or a wall is leak-proof, the aerogel is applied in-between the wall gaps and bricks to increase compression thus sealing the doors and windows [42]. The construction of walls destroys the flame propagation movement and absorbs kinetic energy [35]. The propagation of an acoustic wave is moderated in both amplitude and velocity because of the good compression created by the aerogel blanket [42].

2.4.3 Active engineered safety

Active engineered devices possess more advantages than passive engineered devices [1]. The most prominent is one of detection and alerting, which is used to control the concentration of dust (MEC) or fuel/gas (LFL/UFL) in an atmosphere and ensure that it's below explosible ranges [1], [17]–[19], [32]. They also reduce the concentration of oxygen in the atmosphere by the addition of inerting gasses such as carbon dioxide; nitrogen; argon and helium [17], [35]. When an explosion occurs they detect the projection of the explosion flame and inject an inert gas or suppressants [17], [35]. Active engineered devices can be designed based on their level of sensitivity, low sensitivity sensors may cause the suppression method to fail and high sensitivity can cause unnecessary financial loss [16]. Active engineered barriers consist of sensors; dispensers and suppressants [17].

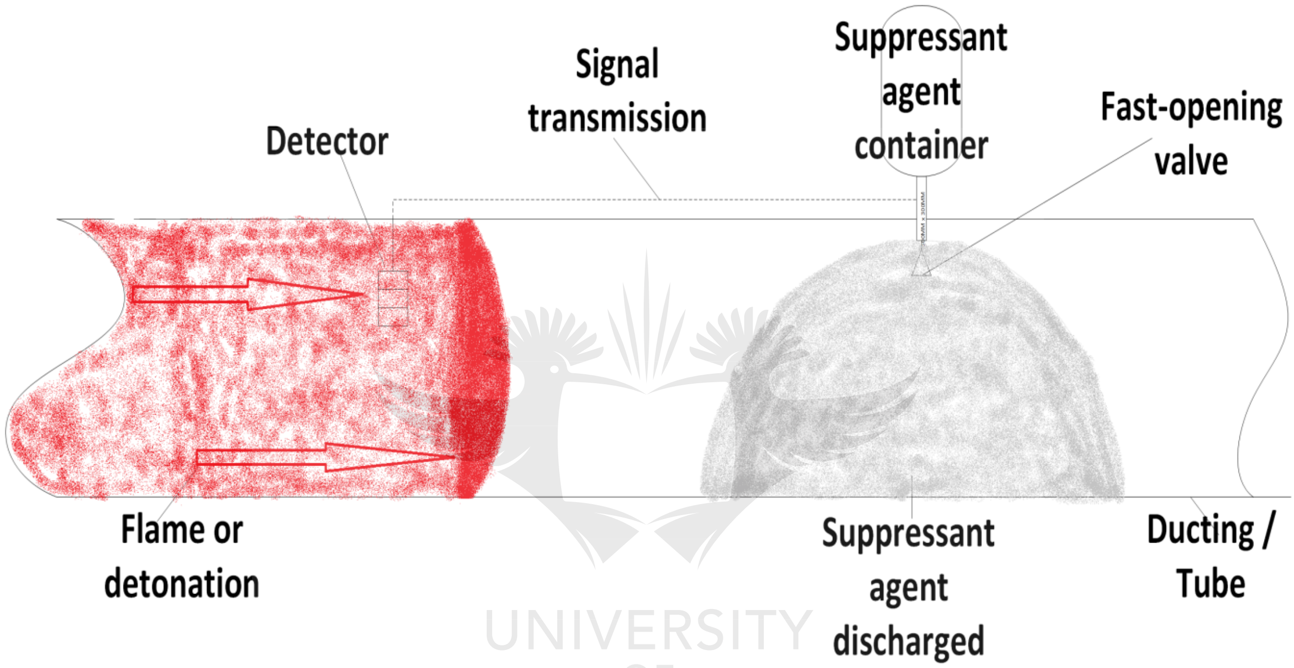

Figure 8: Active inert suppressant agent discharged in the ducting.

Sensors when strategically positioned (**Figure 8**), detect an oncoming explosion by detecting an increase in the following parameters: static pressure; temperature, and radiation [35].
The types of sensors used are thermocouples; thermo-mechanical; ultraviolet; infrared or blast operated sensors [35]. Upon sensing/ detecting the explosion flame or wave, the dispenser is activated [35].

1. Dispensers discharge inert gas or water utilizing compressed gas or a water deluge spray system. Spray nozzles can be strategically positioned across the operating atmosphere, these nozzles based on their sizes can dispense suppressants uniformly across the operating atmosphere area [38].
2. Suppressants are required to match the physical and chemical properties of explosible materials; the suppression efficiency of an active system depends on two core control philosophies: short-time-delay and strong reliability [17], [35]. Other factors that are essential to the success of suppressants are the type of extinguisher materials; triggering pressure; the geometry of the protected area; uniform dispersion at an early stage of combustion [1], [43].

2.4.4 Limitations of active engineered safety

Zou and Panawalage [38], complimented active engineered barriers as the most advantageous preventative option compared to passive barriers. Though, its dependency on electronic control components may create an unsafe condition [38]. For example, if a power outage causes a chemical process reaction runaway or equipment overpressurizing –the unavailability of the active engineered barriers, can result in escalation or domino effect [15]. In the mining industry due to their processing areas being in remote areas, external power sources on the surface of the mine might not be readily available, thus compromising the effectiveness of the active barriers [35], [38]. Moreover, Amyotte and Eckhof [1], stated that these active engineered devices require proper maintenance and testing to facilitate their reliable performance and to ensure continuous operation. Zou and Panawalage [38], recommend that uninterrupted power supply (UPS) systems are used as they are battery operated and can give the response when required regardless of a power outage or not.

Furthermore, Wang *et al* [35] [42], compare passive engineered devices to active engineered devices and suggest that active engineered devices are in practicality inferior compared to passive engineered devices as they are more complex (internal connections) and have a dependency on control systems. A failure in the system is directly related to a failure of the active engineered device [15]. Thus, to ensure that all active engineered devices are fully operational, the end-user needs to ensure that procedures are put in place to maintain and safely operate these devices/ barriers [1], [26].

2.4.5 Procedural safety management

Amyotte and Eckhof [1] suggest, that it is agreed that procedural safety management systems rely on a strong human element during the operations of the process or plant. Procedural safety management is placed at the bottom of **Figure 6** of the hierarchy of loss prevention control, due to the high potential for human error [1]. Hence, the performance of the plant personnel is critical to the success and the safety of the operating atmosphere. Plant personnel should fully comprehend that they are the last line of explosion prevention and mitigation (to monitor anomalies and correct) and simultaneously they are the first-line cause of dust and gas explosion [1], [17].

To reduce the risk of an explosion for a dust and gas process, procedural safety measures to be put in place can be:

- Removing ignition sources – by preventing any hot work by grinder, drill, or welding.
- Removing static source – ensuring building and equipment are bonded and ground to earth. Personal protective equipment (PPE) to be anti-static and static eliminator bar to be installed
- Tools equipment – using the correct tools with anti-spark properties – tools made from copper-beryllium.
- Removing fuel source – if any hot work or unsafe acts are to be carried out – removal of fuel source (dust or gas) is of high significance.
- Standard operating procedure – compiling of a procedure on how tasks are to be carried out and training relevant personnel on the procedure.
- Job-specific assessment – all risks are analyzed and mitigating solutions are suggested and method statement of how tasks will be carried out is compiled

2.4.6 Process safety management (PSM)

Safety management systems are methods used for risk management. Process Safety Management systems typically consist of approximately 10 pillars, that must be fully assessed and complied with to manage the risks As-Low-As-Reasonably-Possible (ALARP) [1], [44]. An organization is required to understand the full extent of risks associated with their process/ plant, once a handover is done from the projects team to the operations team [17]. It is imperative to understand that once the process/plant construction handover is done, a process risk is accepted and will remain until the process/plant is decommissioned [45].
The objective of PSM is to apply safety management principles to identify, understand and control process/ plant hazards. To mitigate the exacerbation of the impact if an incident were to occur [45], [46]. The PSM pillars are:

- Legal Compliance and accountability
- Process Documentation, and Design procedures & standards
- Process risk management and Process and equipment integrity
- Management of Change
- Human factors (training and performance monitoring), Enhancement of process safety knowledge
- Company standards, codes, and regulations
- Incident investigation and Audits and corrective action

The abovementioned pillars are merged into **Figure 6** – recommended by Amyotte and Eckhoff [1], to create **Figure 9** the revised loss prevention hierarchy of controls.

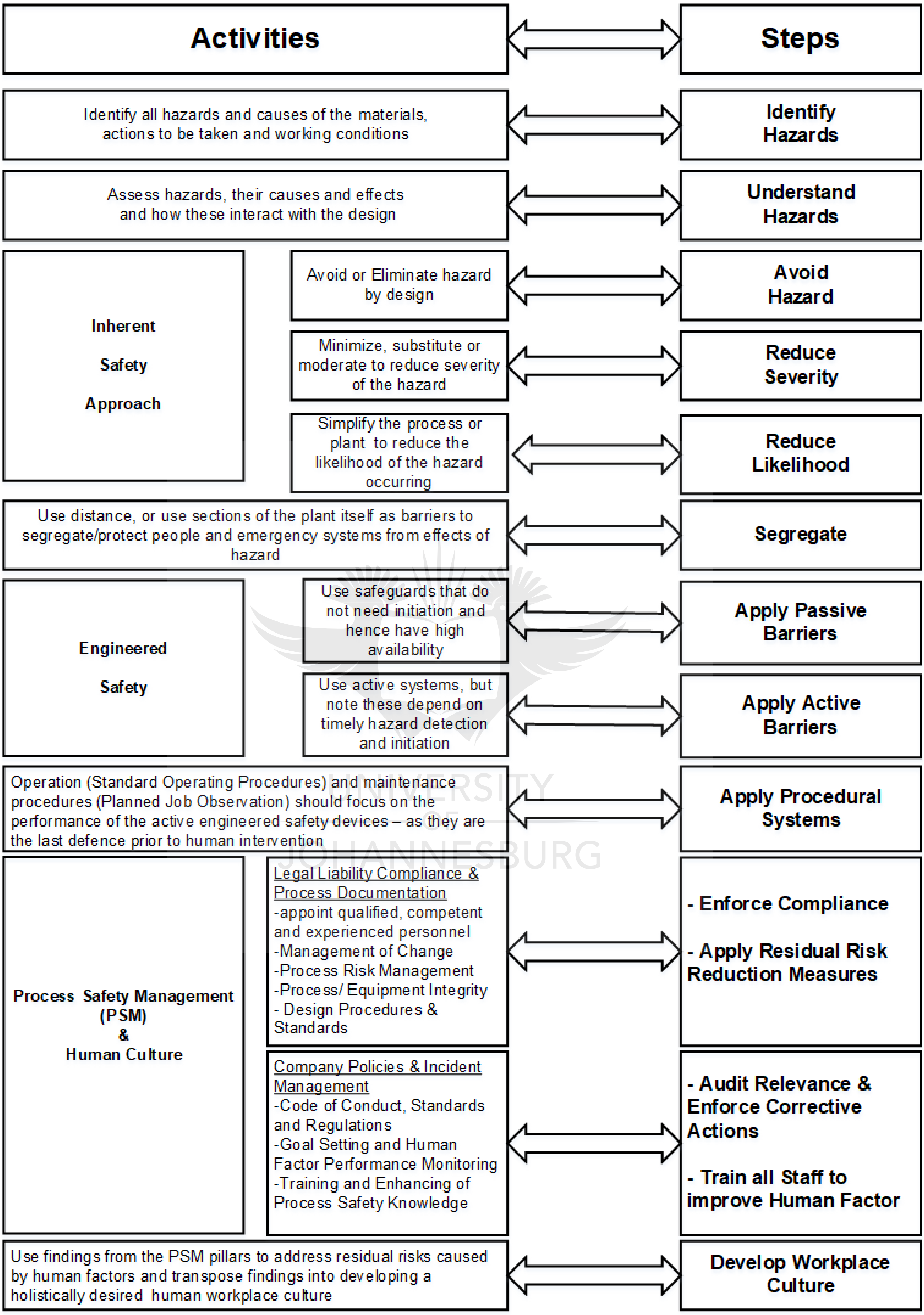

Figure 9: Revised hierarchy of loss prevention control

2.4.7 Human culture (Management and Co-workers) factor

Chen, Qi, and Feng [47] investigated Chinese coal mining incidents which occurred between 1980 and 2000, and the cause of accidents was human-influenced or human behaviors. These human behaviors are negligence, unprofessional conduct, and faulty process/ plant design and accounted for 96% of all Chinese coal mining accidents [47]. Some of the causes were:

- Deliberate violations behaviors that violated the safety systems, i.e. regulations, procedures, etc. Some of the most common ones were: smoking, blasting, or welding without checking gas concentration in the atmosphere.
- Mismanagement was due to management decisions, unsafe production processes, and venting. Such as performing hot work during production, fixing live damaged cables, unauthorized ventilation of explosible gases.
- The faulty design caused accidents when safety loops were not fully tested and verified during the process/ plant commissioning phase.

To achieve a higher safety standard, the management team should develop a culture that facilitates safety consciousness [26].

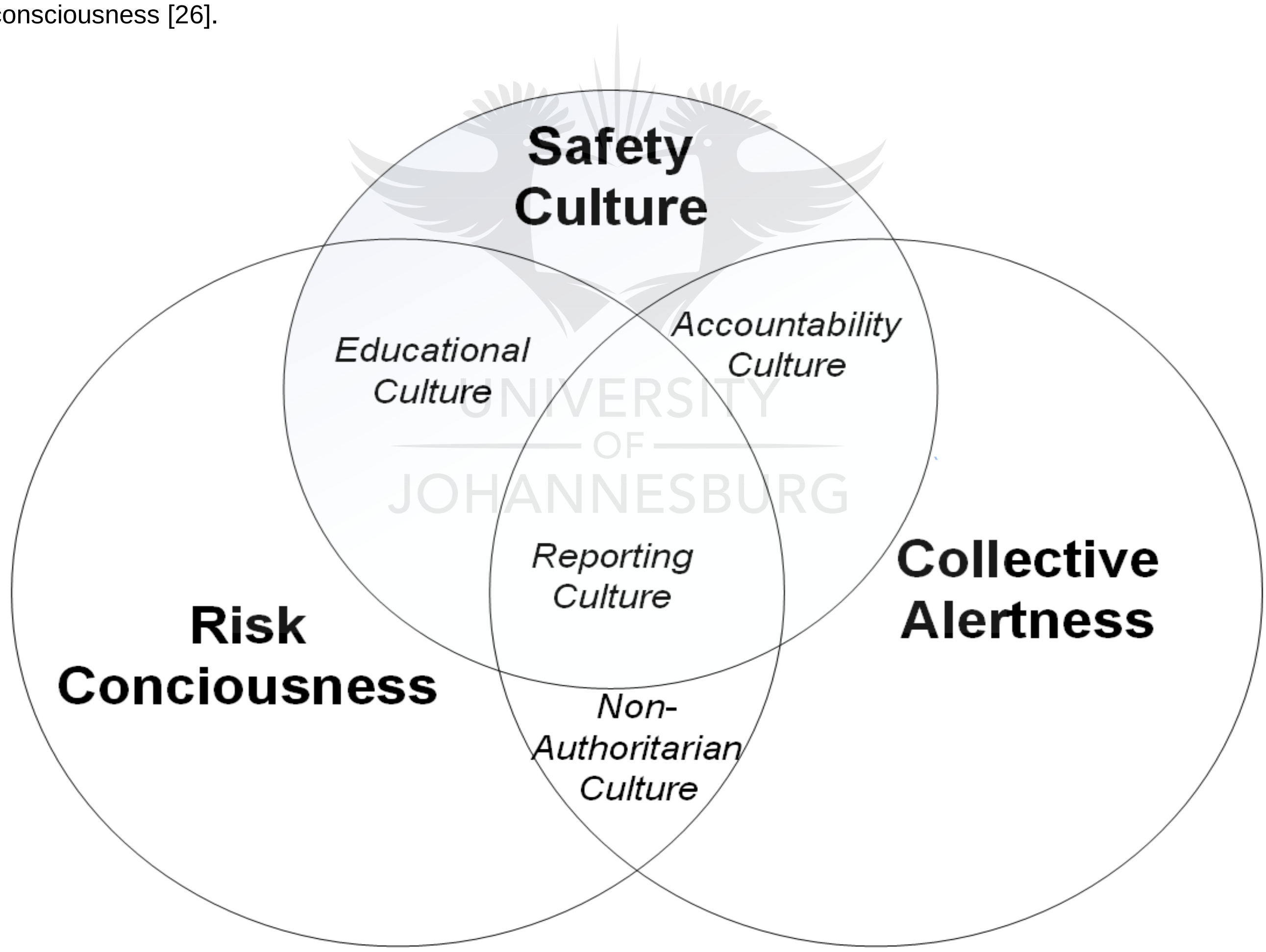

Figure 10: Human factor and safety culture relationship

Figure 10, shows the relationship between the human factor impacts and safety culture. This culture is created by management and championed by the co-workers who do the actual work on the ground/ shop floor [26], [34]. Amyotte and Eckhoff [1], recommended three concepts that can improve a company's health & safety policy, (a) safety culture, (b) collective alertness, and (c) risk consciousness. The three health & safety culture concepts were sub-divided into subcultures: (a) a reporting culture (all near-misses), (b) accountability culture (non-discrimination), (c) educational culture (continuous training – toolbox talks), and (d) a non-authoritarian culture (team collaboration and trust) [1], [34]. For an organization to develop a safety culture, key performance indicators (KPI) address the lack of reporting of unsafe culture [34]. The following section addresses the international and local standards which serve as a guideline to prevent and mitigate dust and gas explosion.

2.5 Global standards

Globalization has allowed for ease of access to information and ease of access to common quality goods and common standard services [48]. To ensure relevancy and consistency of standards, The International Standards Organization (ISO) is responsible for the process of definition; harmonization, and integration of international standards within different sectors [22]. This section covers the two international standards originating from Europe (IEC) and Americas (API) which will be compared to the South African standards.

2.5.1 International Electrotechnical Commission (IEC)

The European directives were implemented during the formation of the European Council in 1957. These directives were accepted into the industry as international standards, International Electrotechnical Commission (IEC) 60079 is responsible for the publications [49]. A problem had been identified of various member states, safety regulations regarding explosible atmospheres. The old approach directives which only applied to electrical equipment, resulted in manufacturers running different tests for different countries' certification standards [50]. Moreover, manufacturers of non-electrical equipment performed a voluntary product certification which leads to a lack of compliance from end-users and in industrial explosions [50]. Bouillard [30], suggested that a need for harmonization of the regulatory standards was identified, thus the development of ATEX (95 & 137) directives. ATEX an acronym for ‘Atmospheres explosibles’ is French for ‘potentially explosible atmospheres’ [20].
ATEX directive 95 also known as (94/9/EC) applies to both electrical and non-electrical equipment, active engineered safety devices, components, and control devices that are designed for use in a potentially explosible atmosphere [20], [50]. It is responsible for the deployment of conformity assessment procedures, which authorized testing individuals to perform and mark the equipment with a ‘CE’ mark for verification of compliance [23]. ATEX directive 95 defines ATEX zones as places in which atmospheres are explosible at different levels of severity, it categorizes explosible zones in terms of dust and gases, however, hybrid mixtures are not considered in this directive [20], [23], [24]. Table 5 below, shows the categorization of ATEX zones and the allowable fuel exposure durations, the zones are categorized as:

- Zone 0/ 20 - gas/ dust continuously present – where explosible is continuously present in the atmosphere for more than 1 000 hours per year;
- Zone 1/ 21 – gas/ dust likely to be present - where explosible is occasionally present in the atmosphere between 10 and 1 000 hours per year and
- Zone 2/ 22 – gas/ dust not likely to occur to be present – where explosible is rarely present in the atmosphere for less than 10 hours per year [23], [51].

Table 5: ATEX zone categories and exposure durations.

Relationship between ATEX Zones			
	Fuel Exposure Durations (hours /year)	ATEX Zone Number	
		Dust	Gases
gas/ dust continuously present	> 1 000 hrs/yr	20	0
gas/ dust likely to be present	10 and 1 000 hrs/yr	21	1
gas/ dust not likely to occur to be present	< 10 hrs/yr	22	2

When area classification is done and all the areas (zones) have been defined based on exposure lengths, the engineers can now determine which equipment is suitable for operation in a specific area (zone). Moreover, engineers can select an explosion prevention solution (e.g. ventilation) to convert an area from an extremely hazardous area - Zone 1/21 to a less hazardous area known as Zone 2/22. Therefore, in general, 80% of all ATEX Zones are set as Zone 2/22 [14]

2.5.2 American Petroleum Institute (API)

In North America, the American Petroleum Institute (API) is deployed to classify hazardous locations [23]. The API works in conjunction with the National Fire Protection Association (NFPA) [23], [49], [52]. These two bodies have published series of explosion and fire prevention standards for each relevant industry processing dust or gas. Tommasini, Pons, and Palamara. [23] states that the first approach for classification is through the implementation of API 500 / API 505 and NFPA 497 / NFPA 499 which states that hazardous locations are to be classified as Class I; Division 1 or Division 2.

- Division 1 – explosible concentrations of flammable dust, gases & vapors can exist under normal conditions [23].
- Division 2 – explosible concentrations of flammable dust, gases & vapor leaks and are present only in rare abnormal process conditions such as over-pressurization due to a cooling tower fan failure or cooling water supply pump failure. The occurrence of the rapture is due to the inability to contain the explosible concentration within a division 1 equipment – resulting in exposure [23].

The North American system classifies explosible atmospheres as divisions [23]. Its standards involve fewer calculations for the application at hand. It also neglects spaces that have a high probability of the presence of combustible gas which can result in over/underestimation of the division [49], [52]. As a result Seitz *et al* [49], found, that since the year 2005 newly built plants/ processes in North America and its allies (government large scale projects) were converting to the internationally recognized IEC 60079 series standard [49] as it is more comprehensive in zone classification. The API standard only has two divisions of classification (Division 1 and 2) which are equivalent to (Zone 0/20 and 2/22) which means the API standard neglects the areas classified as Zone 1/21 in the IEC standard [49]. **Figure 11,** shows the different zones during a road tanker offloading process. The areas marked zone zero are storage containers where the hazardous substance is present. The shaded areas represent the operating area (zone 1) in which hazardous substance is present. The surrounding area is an area that is likely to be hazardous (zone 2).

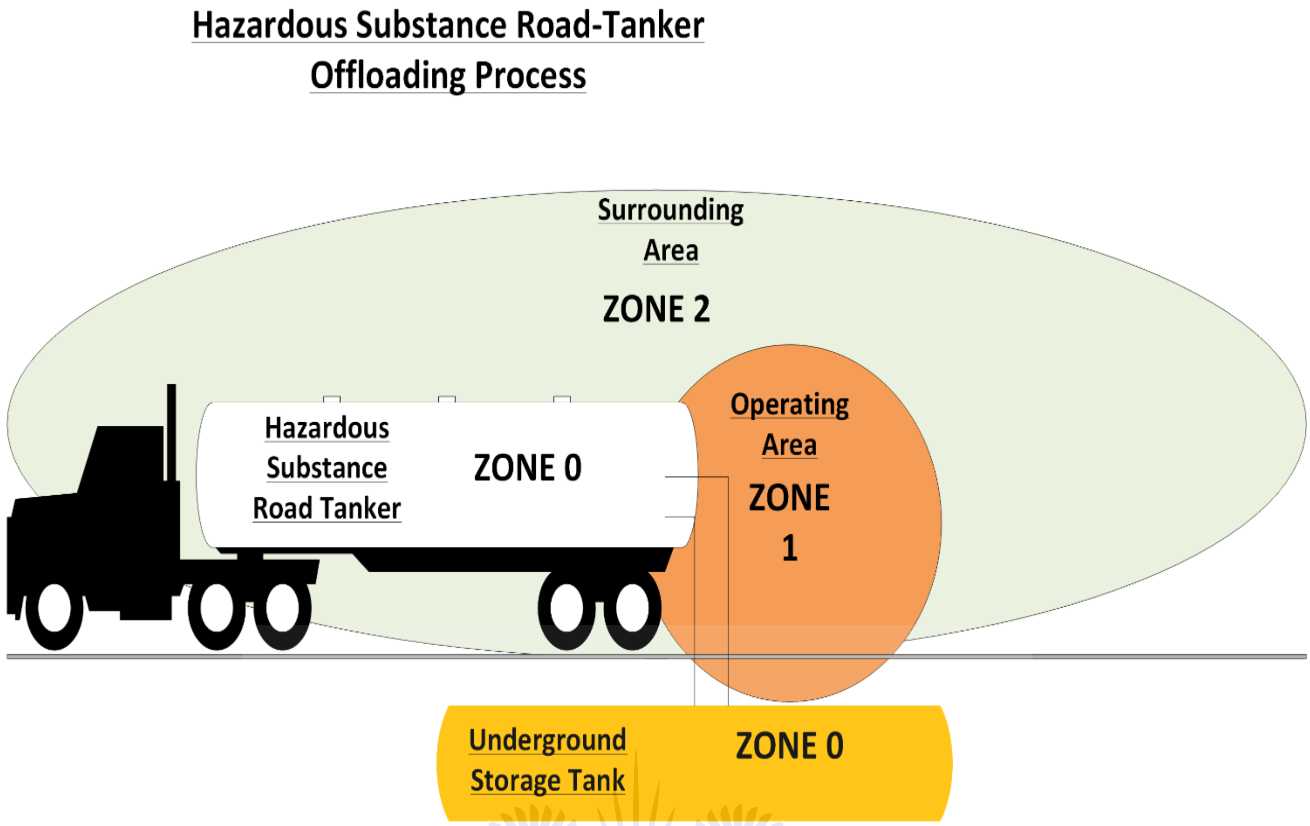

Figure 11: Hazardous substance road tanker offloading process (explosible zones) [14]

2.6 Local standards

This section covered the South African National Standards (SANS), which are published by the South African Bureau of Standards (SABS). The two national standards covered in this section relate to the area classification SANS 10108 and explosion detection; mitigation and prevention SANS 60079

2.6.1 South African National Standard (SANS 10108)

The South African National Standard 10108 covered the classification of areas in which explosions could occur, detailing the proper selection of electrical equipment and mechanical equipment [22]. The standard further detailed the regulations, regarding persons responsible for the risk management of explosion [24], for example :

- EIR 4(1) state - No person shall install an electrical installation other than following a safety standard;
- EMR 8(1) state - No person may use electrical machinery in locations where there is a danger of fire or explosion owing to the present; and
- R21.17.1 state -The manager shall identify and define hazardous areas referred to in regulations [24].

Table 6, shows the regulations which apply to SANS 10108 and the accountable person concerning the government department.

Table 6: SANS10108 and Accountable personnel [24]**.**

South Africa Standard	South African Act	South African Regulation	Accountable Person
SANS 10108	Occupational Health and Safety Act (Act 85 of 1993)	EIR 4(1) EMR 8(1)	Plant Engineer General Manager
SANS 10108	Mine Health and Safety Act (Act 29 of 1996)	R2(1) R21.17.1	Mine Manager/ Plant Engineer General Manager (except in compulsory hazardous locations)
EIR = Electrical Installation Regulations EMR = Electrical Machinery Regulations R = Regulation			

2.6.2 South African National Standard (SANS) 60079 series

The South African National Standard 60079 series comprises 29 sections that cover dust and gas explosions, classification of areas, equipment protection by application electrical installation and maintenance, and gas/dust detection [22]. The standards have been adopted unchanged technically from the international series of IEC 60079 [22].

2.7 Global standards (IEC/API/NFPA) versus Local standard (SANS)

The South African local standards SANS 10108 and SANS 60079 are adopted technically unchanged from the international series of IEC 60079 [22]. The legal status of the standard is relevant to that of South African legislation. The South African standards are identical to those of Australia and New Zealand [22]. So, Benson [28] presents the standards required for the prevention of dust fires and explosions. The compliance standards comprise of American – NFPA; Australian/ New Zealand standards and South African standards referenced from the international IEC 60079 standard. Between the years 2000 and 2005, the Brazilian state-owned company Petrobras – the largest petroleum company in the South American region commenced the conversion of conversion from North American Division standards to the International IEC Zone standards [53]. Therefore, Rangel [53] and Benson [28] presents **Table 7,** which defined the standards to prevent gas fires and explosions caused by electrical/ sparking sources and non-sparking sources of ignition.

The standards presented by Rangel [53] and Benson [28] in **Table 7,** below represent the compliance requirements for the prevention of dust and gas fires and explosions.

Table 7: Critical Standards required for dust and gas explosions prevention.

Standard Code	Scope	Rangel, 2004	Benson, 2012
AS/NZS 4745:2004	Code of practice for handling combustible dust		✓
AS/NZS 3833:2007	The storage and handling of mixed classes of dangerous goods, in packages and intermediate bulk containers-electrical.		✓
NFPA 654	The standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids		✓
SANS 10108	The classification of hazardous locations and the selection of apparatus for use in such locations		✓
NFPA 499	Recommended practice for the classification of combustible dust and hazardous (classified) locations for electrical installations in chemical process areas		✓
IEC 60079-10-2	Explosive atmospheres Part 10–2: classification of areas—combustible dust atmospheres		✓
IEC 60079-0	Explosive atmospheres—Part 0: equipment—general requirements		✓
IEC 60079-1	Explosive atmospheres – Part 1: Equipment protection by a flameproof enclosure that can withstand the internal explosion pressure and prevent –an explosion outside the enclosure [54].	✓	
IEC 60079-2	Explosive atmospheres – Part 2: Equipment protection by pressurized enclosures –where a special protective gas is maintained at a pressure greater than that of the external atmosphere [55].	✓	
IEC 60079-5	Explosive atmospheres – Part 5: Equipment protection by powder filling – where possible ignition sources are surrounded by filling material to prevent the ignition of an external explosive gas atmosphere [56].	✓	
IEC 60079-6	Explosive atmospheres – Part 6: Equipment protection by oil immersion – where parts of the electrical equipment are immersed in a protective liquid in such a way that an explosive gas atmosphere cannot be ignited [57].	✓	
IEC 60079-7	Explosive atmospheres – Part 7: Equipment protection by increased safety – where components are installed to give increased security against the possibility of excessive temperatures and the occurrence of arcs and sparks[58].	✓	

IEC 60079-11	Explosive atmospheres – Part 11: Equipment protection by intrinsic safety – where the type of protection is based on the restriction of electrical energy within equipment and restriction of interconnecting wiring exposed to the explosive atmosphere to a level below that which can cause ignition by either sparking or heating effects [59]	✓	
IEC 60079-15	Explosive atmospheres – Part 15: Equipment protection by various modes of sealing- where the type of protection is based on hermetically sealing, limiting sparks, and restricting breathing (entry of vapors, gas, or mist) [60]	✓	
IEC 60079-17	Explosive atmospheres—Part 17: electrical installations inspection and maintenance		✓
IEC 60079-18	Explosive atmospheres – Part 18: Equipment protection by encapsulation – where the type of protection is by fully enclosing parts that are capable of igniting an explosive atmosphere by either sparking or heating are using a compound or other non-metallic enclosure [61].	✓	
AS/NZS 2381.1:2005	Electrical equipment for explosive gas atmospheres—selection, installation, and maintenance—general requirements		✓
AS/NZS 61241.10:2005	Electrical apparatus for use in the presence of combustible dust—classification of areas where combustible dust are or may be present		✓
AS/NZS 1020:1995 SANS 10123	The control of undesirable static electricity		✓

2.8 Chapter conclusion

This chapter reviewed the literature to give a background of differences and similarities of dust and gas explosion, recommended prevention approaches, and standards. These are required to mitigate the risk presented by the processing of explosible dust and gas products. The dust and gas explosion prevention approaches were reviewed to understand how industrial loss prevention control can be further achieved. Moreover, additional loss prevention approaches were reviewed to understand the impact of the human factor and company culture in explosion prevention. A comparison between local and global standards was done to identify the most relevant global standards. Then, a review of the local standards was done to ensure their relevance – to the global standards. To validate the literature and to identify the knowledge gaps, an analytical survey is discussed in the following chapter.

3 Chapter 3: Research methodology

3.1 Introduction

The current research seeks to identify the prevention approaches used to mitigate dust and gas explosions as per research question 1: *What are the prevention approaches to mitigate dust and gas explosions*. This identifies the various prevention approaches in the hierarchy of loss prevention control ranking from most effective to less effective. Furthermore, research question 2: *What are the gaps that exist between global and local standards on explosion prevention*, identifies the most relevant standard globally and locally. It assisted in identifying the gap between South African standards and global standards. The research methodology selected to perform this research is discussed below.

3.2 Research design

To execute the research effectively, planning and designing the research process is critical to identifying the research method. The consideration of the research questions in chapter 1, is vital for identifying the most suitable research methodology. Du Toit [62], advised a focus on fulfilling the four research paradigms rather than focusing on choosing a subjective research methodology. The research paradigms were: ontology and epistemology, the former is based on reality; and the latter described the relationship between reality and the study and whereby the methodology was a technique used by the study to discover that reality. The four science paradigms are positivism, realism, constructivism, and critical theory [62],

3.3 Research methodology suitable for this research

3.3.1 Survey methodology

This research was conducted using a survey. A survey is defined as a technique for gathering information from a group of participants [63]. A survey is considered as a communication process between the study and respondents, whereby the outcome of this process leads to sharing and comprehension of the relevant topics in question [64].

Various authors [63], [65] stated that a survey research methodology is one of the most important areas of measurement in applied research. The process of execution of the survey began with the structuring of questions and comprehension of the questions to be posed to participants [66]. The respondent retrieval of relevant information from memory was critical as it allowed the participant to feel engaged in the survey [64]. Furthermore, the study was able to determine the respondent's motivation and readiness to be truthful when participating in the survey [64], [67].

3.3.2 Survey design protocol and planning

For the success of this research and achievement of the desired results for data collection. The research aimed to address and consider the following questions [68];

1. What the survey aims to achieve (Objective)?

2. What is the industry to be studied?
3. What the study seeks to know (Research Questions)?
3. How the data will be collected (Methods to be used)?

3.3.3 Objective of survey

The survey study aimed to attain an in-depth understanding of the safety prevention approaches and standards to mitigate dust and gas explosions. The research questions posed in chapter 1 of this report were answered through attaining responses from participants of a survey questionnaire. The survey questionnaire responses were critically analyzed with referral to literature focusing on the hierarchy of loss prevention control proposed by Amyotte and Eckhoff [1].

3.3.4 Industries to be studied

The industry of focus was the edible oil manufacturers and edible oil by-product processors. The study selected the edible oil industry as the researcher was exposed to this environment. Moreover, the presence of hazardous substances (dust; hydrocarbon gas; hydrocarbon liquids, and edible oil) within this industry – implored the need for research. The sample frame may not fully represent the consensus within the industry, because the nature of operations differs between various edible oil manufacturers and processors, although the manufacturing process is the same.

3.3.5 Intention of the study (Research questions)

The current study utilized a survey questionnaire posed to industry professionals and experts on whether the critical safety prevention approaches were known and enforced at the participant's site. Moreover, the industry experts were asked to rate various local and global standards based on their experience and knowledge of the significance of the standards within their organization. The knowledge of prevention approaches and standards were used to determine if a knowledge gap exists in the dust and gas explosion prevention and mitigation approaches.

3.3.6 Data to be gathered

Data collected for this research was quantitatively based on the responses received from the questionnaires which were sent out to participants. A Likert scale was used to categorize the scoring, it offered various advantages such as (a) relatively quick data gathering for a large number of respondents, (b) provided participant’s ability/knowledge estimates [69].

3.3.7 Limitations of the research

Limitations in the research were due to the small sample size of participants within the edible oil industry, this could affect the ability to make statistical conclusions – moreover, lack of response from the selected sample can result in an outcome skewed in one direction [62].

3.4 Design data collection protocol

3.4.1 Methods of data collection

Responses were collected using an online survey questionnaire to compare literature with the received responses. Therefore validating or invalidating the research questions and reaching a conclusion [68]. Data collection methods used were a survey questionnaire and literature [68]. **Figure 12** presents the process of data collection protocol

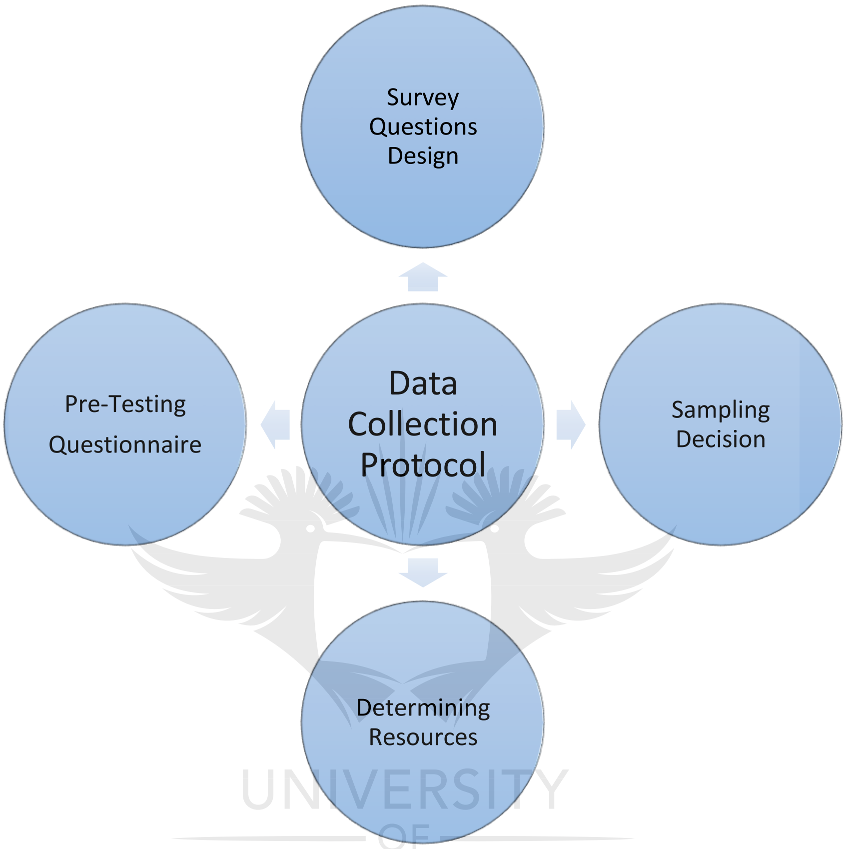

Figure 12: Data collection protocol

3.4.2 Survey questionnaire

The study selected edible oil manufacturers and processors as the sample frame. The study emphasized the question encoding which was in tune with the language of participants [64]. In this case, various engineering safety jargon was used as the level of education of the participants was complex. The survey consisted of two sections. The first section questions were demographics based – focusing on the respondent's job title and company manufacturing process. The second section questions were a combination of process safety knowledge; personnel attitudes and behavioral traits derived from the research questions. **Table 8**, outlined the research questions and perceived outcome.

Table 8: Survey questionnaire design

Question 1	What are the prevention approaches to mitigate dust and gas explosions?	The research question seeks to uncover whether the participants were aware of the prevention approaches within their environment and to determine the amount of usage of these prevention approaches as per **Figure 9.**	Linked with section 2.4 in the literature review.
Question 2	What are the gaps that exist between global and local standards on explosion prevention?	The research question seeks to uncover which standards between global and local standards, do participants deem as significant to implement.	Linked with section 2.5 to 2.7 the literature review

Peterson. [67], argued that the question design aimed to ensure that participants' tasks were simplified by minimizing the reasons for not responding.

3.4.3 Sampling decision

To increase the respondent's comprehension, the study ensured questions and statements were as short as possible [64]. The general advice by Lietz [64], was to ensure the number of words within a survey question was between 16 to 20 words per sentence. Moreover, Peterson [67] advised choosing between the usage of open-end or close-end survey questions, the former being survey questions in which participants used their own words and the latter being survey questions which participants do not use their own words. Close-end survey questions are conducted through a Likert scale. A Likert scale is a psychometric scale that has multiple categories from which participants choose to indicate their opinions, attitudes, or feelings about a particular issue [69]. The industry of focus was the edible oil manufacturers and edible oil by-product processors. The selected sample frame was the edible oil industry as the researcher was exposed to this environment. Moreover, the presence of hazardous substances (dust; hydrocarbon gas; hydrocarbon liquids, and edible oil) within this industry – implored the need for research. The sample frame may not fully represent the general consensus within the industry, because the nature of operations differs between various edible oil manufacturers and processors, although the manufacturing process is the same. There are approximately 13 edible oil manufacturers and processors in the Gauteng province. The sample frame consisted of highly industrialized manufactures and Small Medium Enterprises manufactures. The current study focused on a closed-ended survey. These type of questions were chosen because they minimize need for physical interaction surveys [33]. Expectedly, the current global pandemic COVID-19 – presented limitations as participants at their workplaces were faced with challenges of observing the social distancing rule and lockdown.

3.4.4 Determining resources

To effectively complete the survey data collection, cost planning was imperative. As [66], [67], suggested, to compare the cost of research methods, based on (i) time spent to prepare and perform survey; (ii) amount of money to execute survey and (iii) effort to execute survey – population size and geographic distribution. Web and mail surveys were cheap and quick to execute, these methods were less affected by the variables of population size and geographical distribution. However, based on time mail surveys were less effective as compared to web surveys as they can take up to 8 weeks for response [66], [67]. Regarding telephone and face-to-face interviewing, the latter was less effective as it required training of interviewing personnel; traveling; physical interaction [66], [67]. **Table 9,** shows the comparison of different survey methods based on costs and ethical objection.

Table 9: A comparison of possible survey methods

Survey Method	Financial amount impact	Execution time impact	Effort to execute Size and distribution	Possible ethical objection
Web	Cheap	Quick	Easy – not impacted by size nor distribution	Lack of consent
Mail	Cheap	Long	Moderate – impacted by the respondent.	Lack of consent and breach of privacy
Telephone	Moderate	Quick	Easy – not impacted by size nor distribution	Breach of privacy Use of deception
Face-to-Face	Expensive	Long	Intensive	Use of deception

A combination of two methods was chosen to execute the survey, with the main research methodology being a web-based survey:

- The cover letter and survey link was sent via e-mail
- The survey was hosted on a web-based platform known as www.surveymonkey.com

Once the best method of conducting the survey was chosen, the following phase was to conduct a pre-test of the survey questionnaire [66].

3.4.5 Pre-testing

The pre-testing phase was meant to give the designed survey and sample population a trial to monitor for errors [66]. To prepare for the pre-testing, a sample frame needed to be compiled or identified if it pre-exists for the target population. Lastly, the survey questions were drafted from literature or pre-existing questionnaires from other authors [66], [67]. Czaja and Blair [66] suggested, that during the pre-testing phase one should question how participants would perceive and interpret specific questions – hence testing the survey on fellow peers or colleagues was advised.

3.5 Data collection

Quantitative data was collected through conducting a questionnaire, participants were requested to score and rank statements derived from literature review using the Likert scale. The questionnaire was sent to pre-selected participants within the edible oil industry. The questionnaire was sent to participants through a survey platform– with instructions detailing the sequence of the questions asked. The questionnaire was designed to be easily understood and completed by the participants.

3.5.1 Target population

The current study is to be conducted in South Africa, mainly focusing on the edible oil manufacturers and processors within the Gauteng region. The following professionals were identified as possible participants for the questionnaire: Site Engineers (GCC); Production managers; Engineers (process and safety) and Health and Safety officers.

- The questionnaire was addressed to site engineers as they are legally appointed as per the department of labor regulations to manage and authorize all hazardous work within the site. They are trained and experienced in both mechanical and electrical engineering principles which are critical disciplines within the production environments. They are held responsible for any incidents that occur on-site.
- The questionnaire was addressed to production managers as they are the direct persons in charge of all production areas and human resources. They are experienced in process management and they understand and manage all risks associated with raw materials; by-products and final products within the process.
- The questionnaire was addressed to process/safety engineers who work in close relationships with production managers and health and safety officers. They possess an in-depth understanding of process parameters, equipment design, and functionality. Their duties are to ensure the process is operated, controlled, and managed safely at all times and to minimize the risk posed by contractors – through contractor management standards.
- The questionnaire was addressed to health and safety officers who have first-hand experience of challenges in the production areas. Their duties are to enforce safety regulations through hazard identification and risk assessment – they identify and report non-conformances caused by all employees including management.

The study targeted 10 edible oil manufacturers and processors within the Gauteng region. The table below depicts the notable people involved in the production plants to be studied. The expectation was responses from 20 people will be received.

Table 10: Personnel involved in production plants

People involved in the production	
Site Engineers	5
Production Managers	5
Process / Safety Engineer	5
Health and Safety Officers	5

Refer to the questionnaire attached as appendix A.

3.6 Data analysis

3.6.1 Quantitative data analysis method

Quantitative data analysis presented an opportunity to summarize large amounts of data and to make objective predictions about future trends [62]. Moreover, Du Toit [62] suggested a clear and logical rationale for the procedures be used to arrange and organize such data. Du Toit [62] confirmed, quantitative research as one of the most vital indicators of validity.

The external validity of a quantitative study was threatened by the following problems: population, time, and ecological validity.

- 'Population validity' referred to whether pre-empted conclusions can be drawn from a study of a specific population. The questions analyzed whether a relationship between the studied variables exists in large population size. Moreover; to question whether the validity of the population was affected by the population size being small [62], [70].
- 'Time validity' referred to whether results of a specific study performed at a specified time could be generalized concerning other periods [62], [70]
- 'Environmental validity' referred to the evaluation of environmental factors that contribute to specific incidents [62], [70]. To further evaluate and analyze compound causational reasons of environmental factors that contributed to specific incidents in case study history [70].

3.6.2 Likert scale rankings

Data were analyzed using the Likert scale rankings. Beglar and Nemoto [69], recommended Likert scale range be kept between three scales and six scales. Because Likert scales with more than six category scale are rarely justifiable as they resulted in lack of concentration and memory recapitulation of the participants.

A Likert scale measurement model allowed the evaluation and validation of responses. Beglar and Nemoto [69], suggested two measurement models namely, the True score model and the Rasch model. The true score model is equation-based as per the following equation: Observed score = True score + Error. The Rasch model consists of two models for analyzing Likert-scale data: The partial-credit model and the rating scale model which are available from the Winsteps Software package[69]. Formal measurement models such as the Rasch models are superior compared to the traditional true score model. This study used the true score model for data analysis.

3.6.3 Ethical consideration

Quantitative research involving humans through the utilization of survey questionnaires should be evaluated to ensure that participant's anonymity and confidentiality were maintained. However, anonymity and confidentiality account for a portion of the ethical principles required to ensure participants' protection. There are four ethical principles that a quantitative study thoroughly explored, namely autonomy, beneficence, non-maleficence, and justice.

Autonomy: Participants completed the survey anonymously and no data that enabled the study to identify the respondents or the organization the respondent worked for was collected. Respondents were provided with information about the research to make an informed decision as to whether they wanted to take part or not through the cover letter that was sent with the survey link. Participants who did not want to participate had the right to not complete the survey and withdraw.

Beneficence: The current study conducted, presented an indirect benefit to the participants, as it attempted to increase the knowledge about available explosion prevention approaches and also to offer guidance regarding the recommended global standards to be implemented within the edible oil industry.

Non-maleficence: The current study attempted to validate the existence of a knowledge gap between the local and global explosion prevention approaches for explosion prevention. The survey focused only on questions directly related to explosion prevention approaches and no personal or company data was collected or the geographical location of respondents was collected.

Justice: Industry practitioners responsible for explosion prevention approaches were requested to complete the survey. The survey questions had been derived from literature review activities to ensure no personal opinions were introduced to protect the respondents and ensure no questions can cause harm or embarrassment.

3.7 Chapter conclusion

In this chapter, the research methodology and the process of data collection were presented and explained. To enable the study to answer the research questions presented in chapter one of this research, a questionnaire was designed using categories from the Likert scale. The data obtained through the questionnaire presented a point of view from industry professionals and experts. The obtained data were used to support and validate the data obtained from the analysis of literature.

Industry professionals and experts from the edible oil industry were sent a survey questionnaire to obtain their views on critical prevention and mitigating approaches for dust and gas explosions. Findings from the data analyzed either validated or invalidated the existence of a knowledge gap within the South African standards and regulations compared to International best practices.

Data collected were presented and analyzed in chapter 4 to draw conclusions and make recommendations.

4 Chapter 4: Results and Discussion

4.1 Introduction

The objective of this research was to determine whether a gap existed within the South African local standards when compared with international standards. This was achieved by analyzing the explosion prevention approaches and explosion mitigating techniques. Also, the following research questions were asked: *What are the prevention and mitigating approaches to dust and gas explosions,* and *what are the gaps that exist between global and local standards on explosion prevention.*

This chapter presented the collected data in a less complex manner. The survey questions regarding prevention and mitigating approaches to dust and gas explosions were extracted from the literature. The participants were asked closed-ended question's which revealed their awareness and usage of the prevention and mitigating approaches. Thereby answering the first research question. Moreover, the participants were further asked to recommend local and international standards which they deemed critical for consideration; answering the second research question.

4.2 Participants roles and process conditions

The first question of the questionnaire was designed to understand the role which each respondent is occupying within their respective companies. The second question was designed to understand the processes that each respondent is currently exposed to. A total of 17 professionals within the edible oil industry participated in the survey. The results shown in **Figure 13,** indicate a total of seven site engineers; four process/ safety engineers, four health & safety officer, and two production managers participated in the survey. **Figure 14,** shows that of the 17 respondents 59% are exposed to boiler operations, 41% are exposed to solvent extraction operations and 53% are exposed to refining operations which are processes that contain coal dust, spent clay dust, vegetable seed-husk –meal dust-free fatty acids and hexane solvent which are highly flammable. Respondents exposed to dry silo storage where flammable dust concentrations are excessive were at least 29%. The remaining 41% of respondents exposed to bulk liquid storage and edible oil by-products were exposed to crude oil, refined oil, soapstock, and free fatty acids which are volatile due to the presence of hexane solvent which is a hydrocarbon with low flashing points. Even post refining the refined oil stored in large storage tanks poses a hazard, as refined oil flash point (>250°C) is lower than the heat range (1000°C) of maintenance welding machines. Welding machines are the source of most explosions during maintenance within the edible oil industry [28].

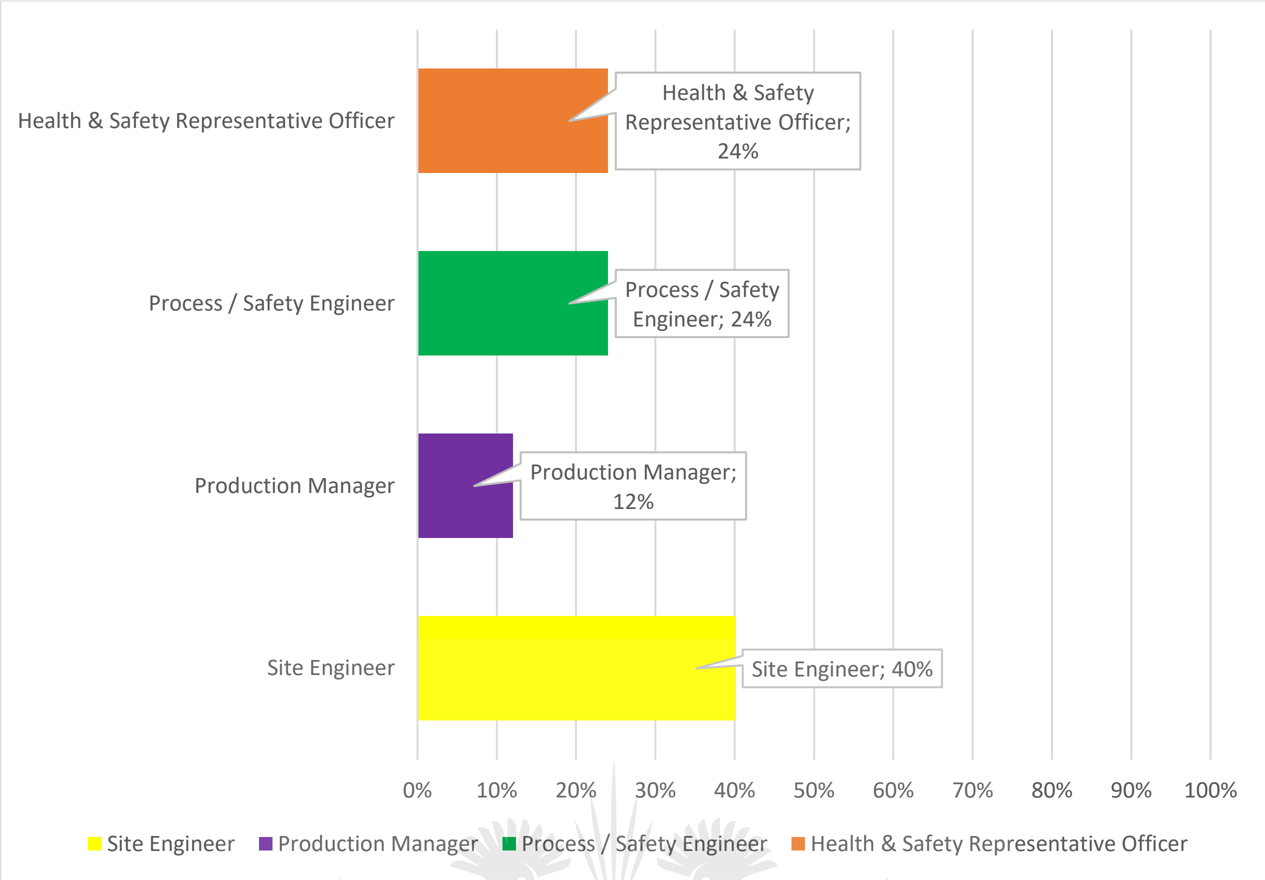

Figure 13: Participants professional roles in the industry

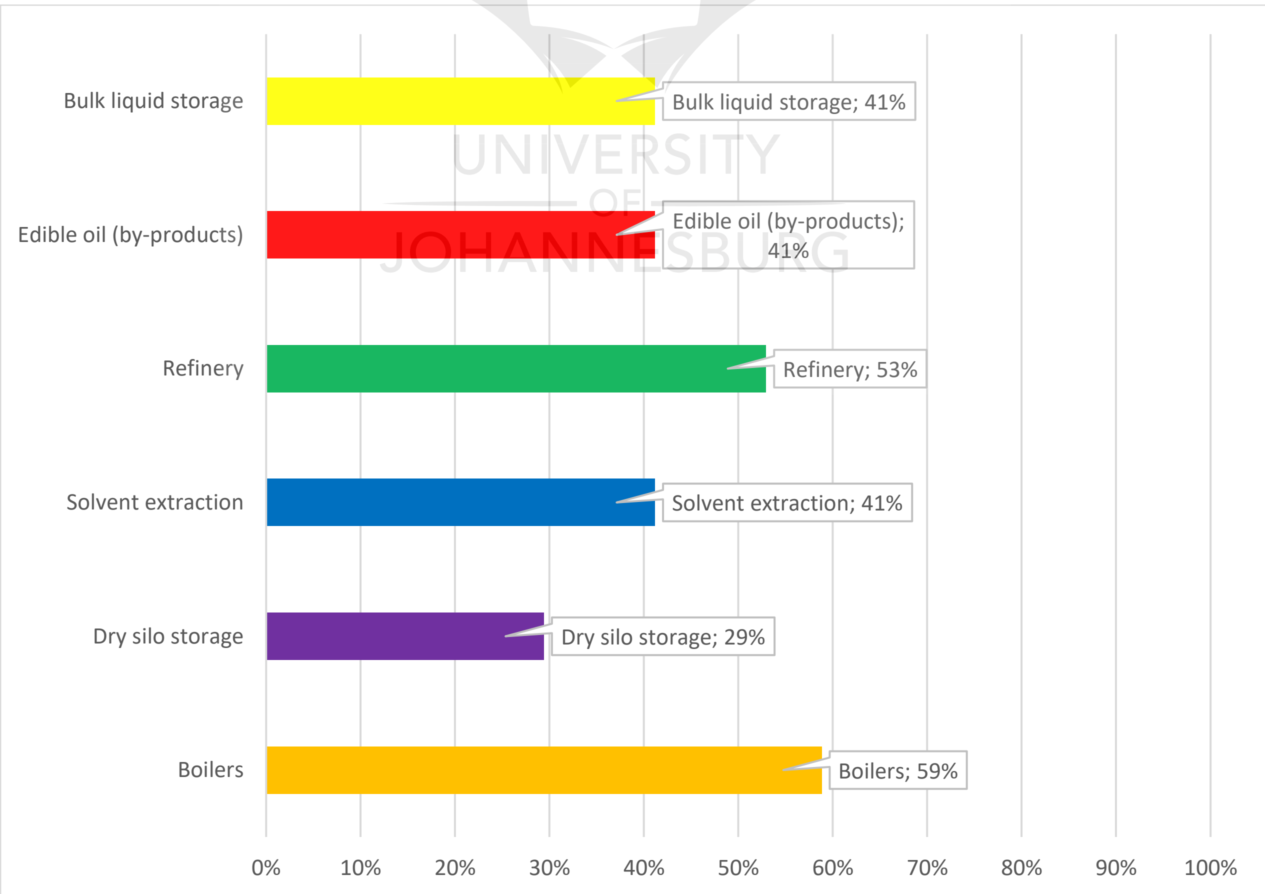

Figure 14: Participants site process operations

4.3 Respondents awareness and utilization of principles related to explosion prevention control

The third and fourth questions of the survey were designed to understand the level of awareness and utilization of each respondent regarding the principles of hierarchy loss prevention control outlined in **Figure 9** in **Chapter 2**. The results below were outlined based on the sub-headlines (2.3.1 to 2.3.7) in **Chapter 2**.

Table 11: Awareness and Utilization of hazard identification & risk assessment

Column A Level of Awareness						Column B Level of Utilization				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Hazard Identification & Risk Assessment:					
0%	6%	18%	47%	29%	Q1: Identifying hazards and unsafe conditions presented by raw materials; chemical solvents; by-products and finished goods.	6%	6%	41%	18%	29%
0%	12%	18%	46%	24%	Q2: Understanding the hazards; causes and effects and how they interact with the holistic site system.	12%	0%	24%	29%	35%

Table 11, above represents the first principle of loss prevention control, which is hazard identification and risk assessment. None of the respondents were unaware of the first principle. Approximately 12 respondents (71%) were confidently aware (eight-moderately aware and five-extremely aware) of the first principle, and 2 respondents (12%) showed a slight awareness of the first principle and the remaining 3 respondents (18%) were unsure of their knowledge of the first principle. However, only 10 of the respondents (47%) utilize the first principle frequently. It further revealed that at least 4 respondents (24%) occasionally participate in hazard identification and risk assessment procedures within their organizations. The lack of utilization of the first principle was only by three respondents' (12%). The survey reveals that three respondent's professional roles were two site engineers and one health and safety officer (H&S). A site engineer is regarded as the highest engineering authority within a processing plant, with knowledge of occupational health and safety regulations. The site engineer is in charge of setting up systems to enforce a safe working environment. An H&S officer is the first line of action at enforcing safe working conditions through monitoring documentation of employees for hazardous work, issuing safe working permits, and monitoring the operators when carrying out hazardous tasks.

Table 12: Awareness and Utilization of inherent and engineered safety approaches

Column A Level of Awareness						Column B Level of Utilization				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Inherent Safety Approach:					
18%	6%	24%	24%	28%	Q3:Area classification -Zoning of Areas	12%	12%	40%	18%	18%
6%	18%	24%	24%	28%	Q4:Hazard Elimination - Avoiding hazard	6%	6%	35%	18%	35%
12%	12%	12%	29%	35%	Q5:Hazard Moderation- Reducing severity	6%	24%	18%	24%	28%
					Engineered Safety Approach:					
0%	24%	12%	40%	24%	Q6:Passive Barriers - Usage of safeguards such as vapor walls; steel structure and double door system	12%	12%	28%	24%	24%
6%	24%	18%	28%	24%	Q7: Active Barriers - Usage of active systems such as fixed detectors; mobile detectors; sprinkling system; ventilation	6%	18%	18%	34%	24%

The second section of the hierarchy of loss prevention control is the inherent safety approach which is the elimination or moderation of hazards at the design phase and also area classifications. It can be expected to find fewer individuals who continuously utilize these approaches as many manufacturing companies utilize consultancy companies for the design of processes and plants and area classifications. **Table 12,** shows that a total of 10 respondents (59%) were confidently aware of the three inherent safety approaches (area classification; hazard moderation, and elimination), while only 6 of the respondents frequently use the three inherent safety approaches. The 6 respondents one is a production manager, two H&S officers, three site engineers, and two production/safety engineers. This data shows an even spread of professionals who utilize this critical step in loss prevention.

The third section of the hierarchy of loss prevention control is the engineered safety approach which includes passive and active barriers. A total of 5 respondents (29%) was extremely aware of passive and active barriers and frequently utilized these barriers. The respondents were made up of one process/ safety engineer; two site engineers; one production manager and one H&S officer. It is expected that these 5 respondents should have an in-depth understanding of the SANS 60079 standards.

Of the remaining 12 respondents, 8 (47%) were somewhat familiar with the barriers and occasionally used the passive and active barriers, while 4 respondents (24%) were slightly aware. The knowledge of the first three sections of the hierarchy of loss prevention control (hazard identification, inherent and engineered safety approaches) is expected to lead to a considerable awareness and usage of the fourth section of the hierarchy of loss prevention control, which is procedural safety. Procedural safety is directly linked to the safety culture [1] that an organization defines for its operations guided by the Department of Labour standards and regulations.

Table 13: Awareness and Utilization of procedural safety management

Column A Level of Awareness						**Column B Level of Utilization**				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Procedural Safety Management:					
6%	6%	12%	35%	41%	Q9: Standard Operating Procedures	6%	0%	18%	29%	47%
0%	12%	18%	24%	46%	Q10: Developing Safe Maintenance Procedures	0%	6%	18%	23%	53%
12%	6%	6%	17%	59%	Q11: Housekeeping Procedures	6%	6%	23%	6%	59%

Of the 17 respondents the results in **Table 13** below, shows that a total of 9 respondents (52%) were confidently aware and fully utilized the tools (standard operating procedures (SOP), safe maintenance procedures, and housekeeping procedures) within procedural safety. Of the 9 respondents, two were production managers; two H&S officers; four site engineers, and one process/ safety engineer. The data concurs with literature that a strong human element is related to procedural safety; as the success or failure of a process is directly related to the performance of plant personnel from management and operators [1]. The results show that only two respondents (12%) who occupy the role of process/ safety engineers were slightly aware and never utilized these procedures. The cause of process/ safety engineers' lack of knowledge and utilization could stem from the lack of training or exposure to such as they contribute less to the daily work tasks of certain professionals [1]. The remaining 6 respondents (35%) were slightly aware and occasionally utilized the procedures. The data shows that the role of management within procedural safety is emphasized within the organizations of the respondents.

However, organizational emphasis regarding procedural safety is imperative but the critical factor for achieving total awareness within the fourth section (procedural safety) is the implementation of the fifth section (process safety management). The fifth section emphasizes the legal appointing of individuals within management as per South African regulation. **Figure 15,** below explains the hierarchy applicable to legal appointments:

To increase awareness of process safety management, legal appointments [24] should be carried out together with the classifications of process risk management which includes the process and equipment integrity certifications [1], [13]. Literature defines the site engineer and head of department as those who are responsible for high-level management of process safety management [24]. **Table 14,** below reveal that of the 17 respondents only 5 respondents (24%) were extremely aware and 3 respondents (18%) were familiar to moderately aware of the process safety management tools. However, a total of 7 respondents (41%) frequently use process safety management tools. These seven respondents are one process/ safety engineer, three site engineers, one H&S officer, and two production managers.

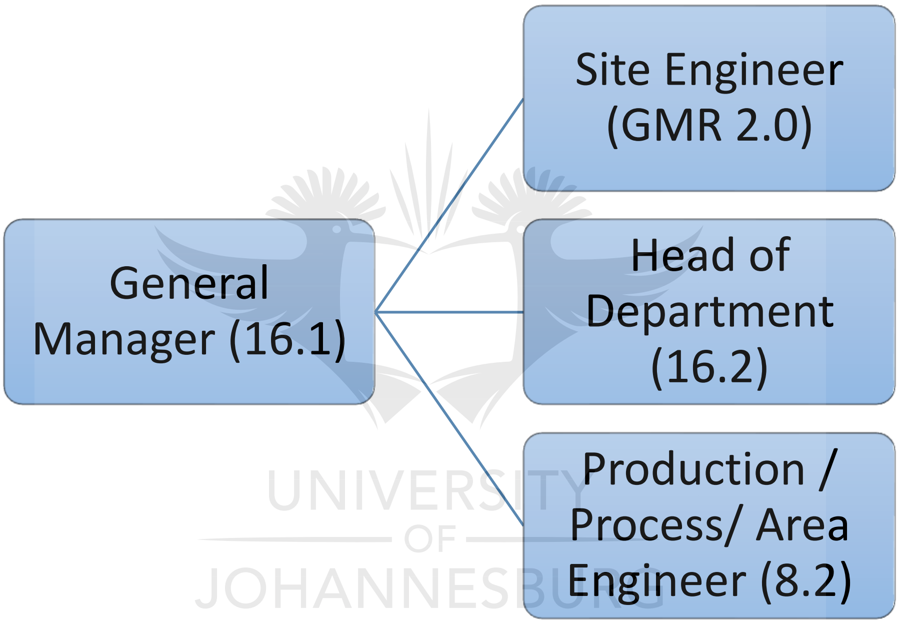

Figure 15: Hierarchy of Legal appointments as per SA Department of Labour

Considering **Figure 15**, results in **Table 14,** validate the literature regarding the professionals who are most likely aware and utilize process safety management tools. However, the distribution of the extremely aware professionals should be larger as the survey was sent to at least 10 organizations and with seven of the respondents (41%) being site engineers and who is the highest authority regarding safety enforcement and implementation as per SA standard and regulations. Two site engineers (12%) were unaware and never used process safety management tools. As per this study, the site engineer was the highest personnel surveyed, hence the expectation that process safety management would be well understood and utilized.

Table 14: Awareness and Utilization of process safety management

Column A Level of Awareness						**Column B Level of Utilization**				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Process Safety Management					
6%	12%	29%	18%	35%	Q12: Legal Liability Compliance - Legal appointments of management personnel	0%	6%	29%	6%	59%
6%	18%	24%	24%	28%	Q13: Process Risk Management	6%	18%	12%	24%	40%
18%	24%	28%	6%	24%	Q14: Process/ Equipment Integrity (Annual re-certification of pressure vessels)	24%	0%	29%	18%	29%

In the last section presented below in **Table 15,** the hierarchy of loss prevention control relates to organizational policies and incident management. As per literature, the study revised the hierarchy of loss prevention control presented by [1] in **Figure 6** To create **Figure 9**, which comprises of human factor influence and training of plant personnel as per individual development goal setting; only, one respondent (6%) was unaware and two respondents (12%) did not utilize the company policies and incident management tools. The results reveal that these two respondents were one H&S officer and one process/ safety engineer. A total of 6 respondents (35%) was extremely aware and utilized the company policies and incident management tools. The distribution in this section should represent more awareness and utilization as most organizations have to enforce code of conducts, standards, and regulations, goal setting, and training.

Table 15: Awareness and Utilization of company policies and incident management

Column A Level of Awareness						Column B Level of Utilization				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Company Policies & Incident Management					
6%	12%	6%	41%	35%	Q15: Code of Conduct and Disciplinary Procedures	0%	0%	30%	30%	40%
0%	6%	12%	47%	35%	Q16: Company standards and Regulations	0%	7%	17%	17%	59%
6%	12%	18%	35%	29%	Q17: Goal setting and Human Factor Performance Monitoring	12%	12%	12%	40%	24%
0%	12%	12%	29%	47%	Q18: Training and Enhancing of Process Safety Knowledge	6%	6%	18%	23%	47%

The positive outcome is that most (10) of the respondents (59%) were familiar and sometimes utilized the company policies and incident management tools. Various authors [1], [13], [31], [71] emphasized the significance of company policies in guiding the safety narrative within a specific organization. Employees are required to be informed of company policies, standards, and regulations, individual performance expectations through goal setting, and disciplinary procedures for violators of policies and procedures. Moreover, continuous training enhances process knowledge and incident reporting and management. More respondents were expected to understand the last section of the hierarchy of loss prevention control as it directly focuses on human resources management. Amyotte and Eckhoff [1] stated that the role of management is imperative to achieving overall safety and the definition of a company safety culture is also imperative as it creates a safe working environment.

4.4 Respondents awareness of local and international safety standards

It was expected from the literature that the distribution on the hierarchy of loss prevention control should represent a similar outcome with the last question of the survey. It focused on the local and international standards. Respondents were asked to rate critical local or international standards based on usage. The results are presented below in **Figure 16**.

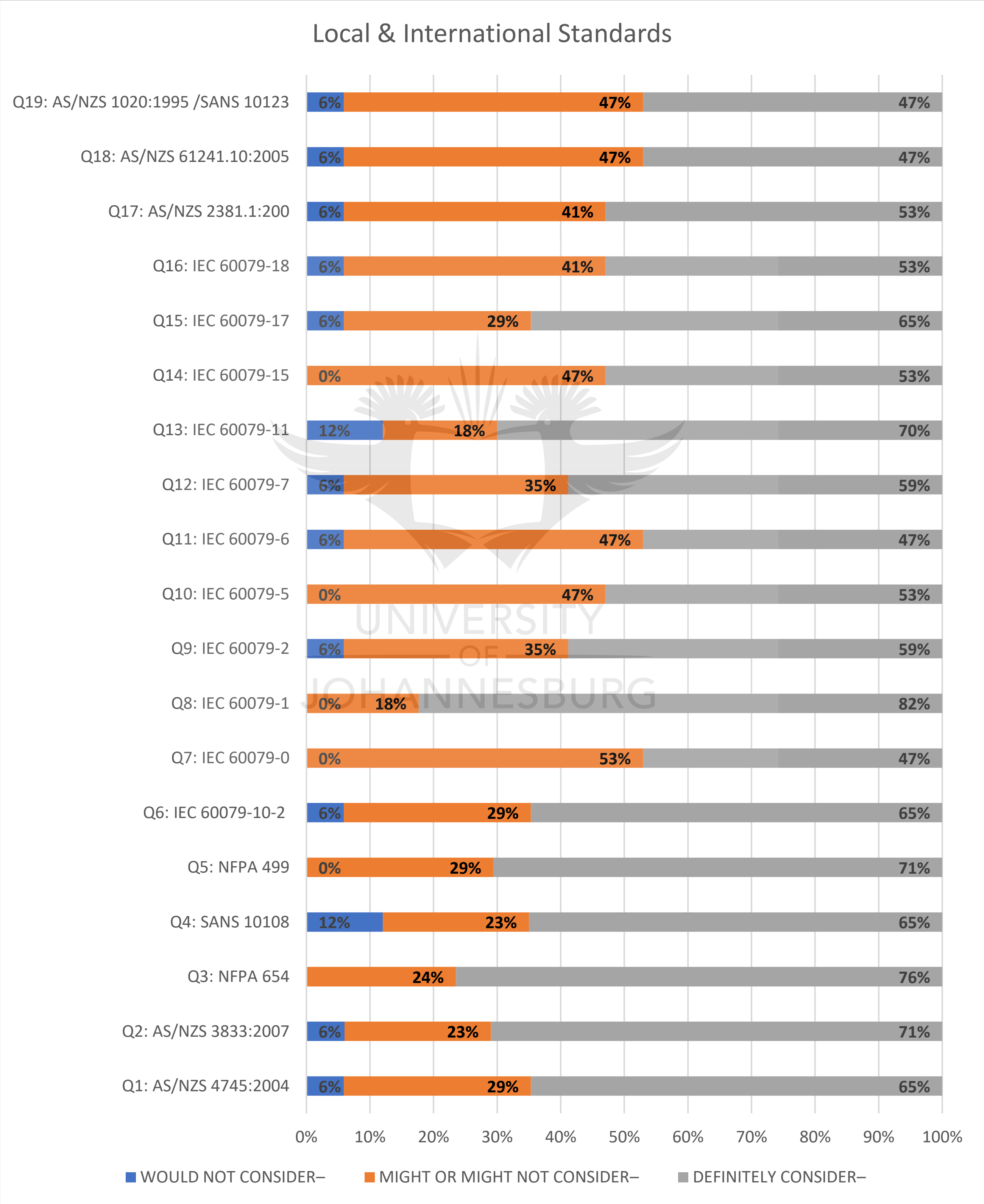

Figure 16: Local & International Standards

To understand which standards the respondents were exposed to, the results were subdivided based on the origin of the standards. Thus, three subdivisions were analyzed which relate to literature in section 2.6 of chapter 2. This includes two international standards bodies (International Electrotechnical Commission and American Petroleum Institute) and (South African National Standards/ Australia New Zealand).

International Electrotechnical Commission

Table 16: International Electrotechnical Commission Standards

	WOULD NOT CONSIDER–	MIGHT OR MIGHT NOT CONSIDER–	DEFINITELY CONSIDER–
IEC 60079-0 - Standard for explosive atmospheres—Part 0: equipment—general requirements	0%	53%	47%
IEC 60079-1 - Standard for explosive atmospheres – Part 1: Equipment protection by flameproof enclosure.	0%	18%	82%
IEC 60079-2 - Standard for explosive atmospheres – Part 2: Equipment protection by pressurized enclosures	6%	35%	59%
IEC 60079-5 - Standard for explosive atmospheres – Part 5: Equipment protection by powder filling.	0%	47%	53%
IEC 60079-6 - Standard for explosive atmospheres – Part 6: Equipment protection by oil immersion.	6%	47%	47%
IEC 60079-7 - Standard for explosive atmospheres – Part 7: Equipment protection by increased safety.	6%	35%	59%
IEC 60079-10-2 - Standard for explosive atmospheres Part 10–2: classification of areas—combustible dust atmospheres	6%	29%	65%
IEC 60079-11 - Standard for explosive atmospheres – Part 11: Equipment protection by intrinsic safety	12%	18%	70%
IEC 60079-15 - Standard for explosive atmospheres – Part 15: Equipment protection by various modes of sealing.	0%	47%	53%
IEC 60079-17 - Standard for explosive atmospheres—Part 17: electrical installations inspection and maintenance	6%	29%	65%
IEC 60079-18 - 6Standard for explosive atmospheres – Part 18: Equipment protection by encapsulation.	6%	41%	53%

Table 16, represents the IEC standards that were most common within the industry as these standards were used as guidelines for the South African local standards. A total of 10 respondents (58%) would consider all 11 IEC standards. Fourteen respondents (82%) showed more consideration for IEC-60079-1, a standard for explosive atmospheres – Part 1: Equipment protection by flameproof enclosure, and 12 respondents considered IEC 60079-

11 - Standard for explosive atmospheres – Part 11: Equipment protection by intrinsic safety/. These standards were common for most passive and active barriers systems (engineered safety approach) which 12 respondents (71%) above confirmed knowledge of in **Table 12**. It is concerning that a total of 9 respondents (53%) were unsure whether they would consider IEC 60079-0 - Standard for explosive atmospheres—Part 0: equipment—general requirements-, as this is the basic summary of the 11 standards. These respondents were 4 site engineers, 1 production manager, 2 production/safety engineers, and 2 H&S officers. Based on **Table 12,** it was expected for less than 6 respondents to consider IEC 60079-5 - Standard for explosive atmospheres – Part 5: Equipment protection by powder filling; as only 5 respondents confirmed working with dry silo storage. However, a total of 9 respondents confirmed consideration of the standard.

American Standards

Table 17: American Standards

	WOULD NOT CONSIDER–	MIGHT OR MIGHT NOT CONSIDER–	DEFINITELY CONSIDER–
NFPA 654 - Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids	0%	24%	76%
NFPA 499 - Standard for the classification of combustible dust and of hazardous (classified) locations for electrical installations in chemical process areas	0%	29%	71%

Table 17, above represents the knowledge that respondents possess regarding American standards. It can be seen that a total of 12 respondents (71%) were aware of the NFPA regulations regarding dust and hazard chemical classifications. Only 5 respondents were not confident regarding the consideration of NFPA regulations. The distribution shows that of the 5 respondents not sure two were H&S officers, and one site engineer, one production manager, and one process/safety engineer. The reason could be lack of exposure to international standards due to the company being fully South African owned and with lack of international exposure. Of the companies surveyed two companies had little to no international management or exposure. The knowledge of the NFPA showed that respondents were exposed to American standards which could be due to the regulation that enforces organizations to appoint a fire engineer to facilitate the study, validation, and implementation of an organizational crisis and disaster management policy.

SANS/AS/NZ Standards

Table 18, below shows a total of 10 respondents (59%) confirmed consideration of the South African; Australia/New Zealand standards recommended by the IEC. However, 6 respondents (35%) were not sure whether they would consider the South African; Australia/New Zealand standards recommended by the IEC. Only 1 respondent would not consider SANS 10108 - Standard for the classification of hazardous locations and the selection of apparatus for use in such locations

Table 18: SANS/AS/NZ Standards

	WOULD NOT CONSIDER–	MIGHT OR MIGHT NOT CONSIDER–	DEFINITELY CONSIDER–
SANS 10108 - Standard for the classification of hazardous locations and the selection of apparatus for use in such locations	12%	23%	65%
AS/NZS 4745:2004 - Standard for handling of combustible dusts	6%	29%	65%
AS/NZS 3833:2007 - Standard for the storage and handling of mixed classes of dangerous goods.	6%	24%	70%
AS/NZS 2381.1:2005 - Standard for electrical equipment within explosive gas atmospheres—selection, installation, and maintenance—general requirements	6%	41%	53%
AS/NZS 61241.10:2005 - Standard for electrical apparatus for use in the presence of combustible dust—classification of areas where combustible dusts are or may be present	6%	47%	47%
AS/NZS 1020:1995 /SANS 10123 - Standard for the control of undesirable static electricity	6%	47%	47%

4.5 Discussion

The results obtained from the survey were not consistent with the literature. The size of the sample selected could be too small or participants' work experience could be of entry to intermediate level.

- Findings showed that all respondents were aware of the first principle of loss prevention and 65% of respondents utilized the first principle – hazard identification and risk assessment. Awareness and utilization of the first principle are vital as it means participants can classify hazards and assess the risk posed by the hazards.
- The lack of utilization (35%) of the second principle of loss prevention control was noted and the possible cause is due to manufacturing and processing companies outsourcing process design and project management to Engineering Procurement Consulting Management (EPCM) companies.
- Furthermore, it was noted that the lack of awareness and utilization (40%) of the third principle (passive barriers) suggests that the organizations surveyed possibly outsource the design and project management to EPCM companies.

Passive barriers are strategically positioned and most of the time passive barriers are in a form of main plant steel structure, equipment positioning, and plant walkways, which are identified and confirmed during the design phase of a process/plant.

- However, it shows that at least 10 respondents were aware of active barriers – this could be influenced by the type of active barriers utilized – these are easy to identify, they are continuously active – giving feedback to the end-user and form part of the emergency plan.
- All the respondents were aware of the fourth principle of loss prevention – procedural safety management. Only 2 respondents were not aware and did not utilize the procedural safety management principles.

- A total of 55% of the respondents showed awareness of their legal liability and it is expected that they have been officially appointed as they frequently utilize the legal compliance.
- Furthermore, it was noted that 65% of respondents were aware of the first principles, this corresponds with the feedback received regarding the fifth principle of process risk management
- Most of the respondents (82%) were aware of the sixth principle of loss prevention. It is expected that respondents be aware of company policies as their roles in the organizations is that of middle and senior management.
- Only 1 respondent (6%) would not recommend IEC and SANS/AU/NZ standards
- A total of 6 respondents (35%) might or might not consider IEC and SANS/AU/NZ standards
- A total of 10 respondents (59%) definitely would consider IEC and SANS/AU/NZ standards
- All of the respondents would recommend American standards, however, a total of 5 respondents (27%) might or might not consider American standards.
- A total of 12 respondents (73%) definitely would consider American standards.

Respondents' knowledge of the principles of loss prevention was noted to be average and required further reiteration and re-training. The respondents showed an overwhelming knowledge of American standards, with none of the respondents negatively rating the American standards. Furthermore, the respondents showed that they understood the similarities of the IEC and SANS standards. The results are conclusive that the relation between IEC and SANS is understood.
However, respondents who were not confident about their awareness and utilization are a total of 4 respondents (25%).

4.6 Chapter conclusion

In this chapter, data collected through survey questionnaires and literature were analyzed and results presented. Findings show that at least 10 respondents were aware of the first principle of loss prevention – hazard identification and risk assessment.
At least 12 respondents (73%) would consider American standards – this is inconsistent with literature, as South African national standards recommend IEC standards above American standards.
However, only 10 respondents (59%) would consider both IEC and SANS/AU/NZ standards, this is consistent with the literature as IEC standards are a benchmarking for SANS/AU/NZ standards.

Literature has shown a drive to implement IEC standards instead of American standards [53], [72]. The fact that almost all respondents were aware of American standards could mean that errors can be made when classifying hazardous zones and implementing principles of loss prevention.

The following chapter presents conclusions based on the findings and provides a recommendation for the research study.

5 Chapter 5: Conclusion and recommendations

5.1 Summary of research objectives

This chapter presents a summary of the research objectives and recommendations to be implemented. The purpose of the research was to identify and establish the existing gaps between South Africa and global best practices on the causes, prevention, and mitigation of dust and gas explosions. It explored the awareness of various regulations that are prescribed by the South African National Standards and investigated the utilization by industry experts as compared to prescribed international regulations and standards

The two research questions which were examined to assist in effectively completing this study were as follows:

1. What are the prevention and mitigation approaches to dust and gas explosions?
2. What are the variations between global and local standards on explosion prevention?

5.2 Findings to research question 1

What are the prevention and mitigation approaches to dust and gas explosions?

The research question strived to define international best practice prevention and mitigation approaches as per past and recent literature review was done in chapter 2. A survey questionnaire was generated by using the reviewed hierarchy of loss prevention control principles suggested by Amyotte and Eckhoff [1] presented in **Figure 9**. The survey questionnaire was used to investigate the existence of the knowledge gap within South African industry experts and professionals. **Figure 17**, below shows the feedback from respondents with knowledge gaps color-coded.

5.2.1 Gap 1: Inherent safety approach

A significant gap exists in the second section of the hierarchy of loss prevention control which is the inherent safety approach. Elimination or moderation of hazards at the design phase and also area classifications. Respondents showed a lack of awareness and utilization of area classification information. The lack of exposure can be attributed to production companies outsourcing the design of processes and plants and area classifications to consultancy companies. This knowledge gap within industry professionals can be detrimental – as accidents can occur in areas that required re-zoning (area classification) and segregation when performing site upgrades. Industrial accidents [7][8][9]–[12] referred to in chapter 1, are typical examples of explosions occurrences. Various authors, Auret [24], Junior [72], and Rangel [73] recommend area classification to be done by specialists as it is complex in some cases. However, organizations may not always seek the expertise of area classification experts for a small plant or site upgrades.

5.2.2 Gap 2: Engineered safety approach

Responses noted on questions 6 and 7 which covered the third principle of the hierarchy of loss prevention control, show that 11 respondents (65%) responded confidently in awareness of passive barriers, but only 8 respondents frequently utilize and 3 respondents who responded in awareness of passive barriers. This shows that respondents lack awareness of the importance of passive barriers that are within their systems. This can result in poor decision-making when encountering an emergency- as the knowledge of the safer areas of the plants or site is critical. One respondent who responded to utilize active barriers showed a lack of awareness. This shows a risk as the professional is not confident of their awareness yet they utilize active engineered systems. Lack of awareness can lead to a lack of knowledge of calibration and usage of portable and fixed dust and gas detection systems and operating principles, thus leading to inconsistent readings from portable and fixed active engineered systems and consequent misapplication of active engineered systems

Figure 17: Hierarchy of loss prevention control respondents feedback

5.2.3 Gap 3: Process safety management

Inconsistent responses were noted on questions 12 and 13 which covered the fifth principle of the hierarchy of loss prevention focusing on legal liability compliance (permit to work procedure), management of change, and process risk management. It was noted that 9 respondents (53%) showed confident awareness but 11 respondents (65%) utilized the principles. The 2 respondents showed utilization of permit to work issuance procedures but lack awareness of legal liability compliance. The gap exists as organizations are required to ensure awareness and legal appointments of management as per **Figure 15**. It was further noted that there was poor awareness of process and equipment integrity, as only 5 respondents (29%) showed awareness. However, 8 respondents (47%) showed utilization of the annual recertification of pressure vessels. The results show a gap exists as less than 50% of the respondents showed awareness to pressure vessel re-certification, moreover, 3 respondents showed inconsistencies, of utilizing yet without awareness of the reasons, and the importance.

5.3 Findings to research question 2

What are the gaps that exist between global and local standards on explosion prevention?
The research question strived to identify variations between global and local standards on explosion prevention as per past and recent literature review was done in chapter 2. A survey questionnaire was generated by using the identified and suggested standards by various experts and authors [24], [28], [73] presented in **Table 7** in chapter 2. The survey questionnaire was used to identify if a knowledge gap existed among South African industry experts and professionals.
Research question 2, has no significant gap as the results show that respondents are practicing, it was noted that the level of awareness was lower than the usage.

5.4 Conclusion

The key finding derived from this research has answered the research questions posed. The limitations of the study were due to the small sample frame. Limiting the amount of expert respondent's participation in the survey across the industry. The problem statement was; **There exists a knowledge gap between international best practices to prevent and mitigate dust and gas explosions and the South African local explosion regulations**.
Literature shows that South African National Standards (SANS) are derived from SABS which is an affiliate of the International Electrotechnical Commission. Thus, standards are published under the IEC, with minimum modifications.
Gaps were identified in the explosion prevention and mitigation approach principles namely; inherent safety approach, engineered safety approach, and process safety management approach. Furthermore, it was identified that a gap exists in the monitoring, compliance, and auditing by the regulatory bodies. Data obtained from the Department of labor regarding occupational fatalities and injuries is insufficient and inconsistent. News reports were used to classify fatalities that were caused by explosions in the edible oil industries in the past decade.
The results obtained have shed a light on the participant's awareness, utilization, and consideration of prevention and mitigation approaches as well as the international best standards. It can be noted that a knowledge gap exists in the industry regarding the best practice standards, prevention, and mitigating approaches.

5.5 Recommendations

This study recommends that further research be carried out with a larger sample frame. Moreover, the survey questionnaire can include additional demographics questions regarding years of service or overall experience in industry and tertiary qualification discipline. This will allow us to compare the results based on years of service and profession. Which can result in better recommendations at minimizing the knowledge gap in the industry.

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APPENDIX A. Cover Letter

<u>To: Participants</u>

I am a Master in (Engineering Management) student at the Faculty of Engineering and the Built Environment at the University of Johannesburg. As part of my studies, I am conducting a research project using a survey questionnaire that aims to verify the types of dust and gas explosion prevention approaches implemented in edible oil factories. Furthermore, the questionnaire seeks to validate the standards implemented at the edible oil factories for risk management. I would like to request your participation in this survey. The research at hand seeks to investigate the effectiveness of installed prevention approaches in edible oil factories, such as active and passive engineered safety devices; procedural safety; process safety management, and the role of human culture within the workplace. The objective of this study will be to determine if a gap exists between South African standards and global standards.

The recommendations from this research will allow for the identified gaps to be addressed through integrating internationally recognized explosion prevention approaches and standards with the South African local standards. Your contribution to the questionnaire will improve the accuracy and success of this research. Your response is vital and there are no answers considered as wrong or right. Participants are guaranteed that this survey is both confidential and anonymous. No information will be disclosed; regarding the company, the location, the health and safety representative; the safety manager, or the production engineer/manager.

There is no need to enter any personal particulars on the questionnaire. Your participation is completely voluntary and you may withdraw from the survey at any stage. Your contribution is highly valued.

Yours Faithfully,

Hulisani Muvhango

<u>hulisanimuvhango@gmail.com</u>

APPENDIX B. Survey Questions

Section 1

Respondent's Profile

Please indicate your role in the company

Please use a tick (✓) next to your answer

	Role in factory	Please Tick appropriate box
1	Site Engineer	
2	Production Manager	
3	Process / Safety Engineer	
4	Health & Safety Representative Officer	

Please indicate the availability of the following processes on your site

Please use a tick (✓) next to your answer

	Processing Plants Classifications	Please Tick appropriate box
1	Boilers	
2	Dry Silo storage & Crushing	
3	Solvent Extraction	
4	Refinery	
5	Edible Oil (By-Products)	

Section 2

Please rate column A according to the level of awareness:

1: Not at all aware, 2-Slightly aware, 3-Somewhat familiar, 4-Moderately aware, 5- Extremely aware

Please rate column B according to the amount of use:

1: Never use, 2-Almost never, 3-Occasionally/Sometimes, 4-Almost every time, 5- Frequent use

Column A **What is your level of awareness regarding the dust and gas explosion prevention approaches?**						Column B **To what extent do you utilize the dust and gas explosion prevention principles and equipment?**				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control.**	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Hazard Identification & Risk Assessment:					
1	2	3	4	5	Q1: Identifying hazards and unsafe conditions presented by raw materials; chemical solvents; by-products and finished goods.	1	2	3	4	5
1	2	3	4	5	Q2: Understanding the hazards; causes and effects and how they interact with the holistic site system.	1	2	3	4	5
					Inherent Safety Approach:					
1	2	3	4	5	Q3:Area classification -Zoning of Areas	1	2	3	4	5
1	2	3	4	5	Q4:Hazard Elimination - Avoiding hazard	1	2	3	4	5
1	2	3	4	5	Q5:Hazard Moderation- Reducing severity	1	2	3	4	5
					Engineered Safety Approach:					
1	2	3	4	5	Q6:Passive Barriers - Usage of safeguards such as vapor walls; steel structure and double door system	1	2	3	4	5
1	2	3	4	5	Q7: Active Barriers - Usage of active systems such as .fixed detectors; mobile detectors; sprinkling system; ventilation	1	2	3	4	5

Column A **What is your level of awareness regarding the dust and gas explosion prevention approaches**						**Column B** **To what extent do you utilize the dust and gas explosion prevention principles and equipment**?				
(1) Not at all aware	(2) Slightly aware	(3) Somewhat familiar	(4) Moderately aware	(5) Extremely aware	**Principles related to dust and gas explosion prevention control**.	(1) Never use	(2) Almost never	(3) Sometimes	(4) Almost every time	(5) Frequently Use
					Procedural Safety Management:					
1	2	3	4	5	Q9: Standard Operating Procedures	1	2	3	4	5
1	2	3	4	5	Q10: Developing Safe Maintenance Procedures	**1**	2	3	4	5
1	2	3	4	5	Q11: Housekeeping Procedures	**1**	2	3	4	5
					Process Safety Management					
1	2	3	4	5	Q12: Legal Liability Compliance - Legal appointments of management personnel	1	2	3	4	5
1	2	3	4	5	Q13: Process Risk Management	1	2	3	4	5
1	2	3	4	5	Q14: Process/ Equipment Integrity (Annual re-certification of pressure vessels)	1	2	3	4	5
					Company Policies & Incident Management					
1	2	3	4	5	Q15: Code of Conduct and Disciplinary Procedures	1	2	3	4	5
1	2	3	4	5	Q16: Company standards and Regulations	1	2	3	4	5
1	2	3	4	5	Q17: Goal setting and Human Factor Performance Monitoring	1	2	3	4	5
1	2	3	4	5	Q18: Training and Enhancing of Process Safety Knowledge	1	2	3	4	5

Implementation and enforcement of recommended standards:

Please rate below standard codes & scope according to the level of consideration: Would not consider, might or might not consider, definitely consider.

Please use a tick (✓)next to your answer.

Standard Code	**Scope of standard**	**Would not consider**	**Might or might not consider**	**Definitely consider**
AS/NZS 4745:2004	Standard for handling of combustible dusts			
AS/NZS 3833:2007	Standard for the storage and handling of mixed classes of dangerous goods.			
NFPA 654	Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids			
SANS 10108	Standard for the classification of hazardous locations and the selection of apparatus for use in such locations			
NFPA 499	Standard for the classification of combustible dusts and of hazardous (classified) locations for electrical installations in chemical process areas			
IEC 60079-10-2	Standard for explosive atmospheres Part 10–2: classification of areas—combustible dust atmospheres			
IEC 60079-0	Standard for explosive atmospheres—Part 0: equipment—general requirements			
IEC 60079-1	Standard for explosive atmospheres – Part 1: Equipment protection by flameproof enclosure.			
IEC 60079-2	Standard for explosive atmospheres – Part 2: Equipment protection by pressurized enclosures			
IEC 60079-5	Standard for explosive atmospheres – Part 5: Equipment protection by powder filling.			
IEC 60079-6	Standard for explosive atmospheres – Part 6: Equipment protection by oil immersion.			
IEC 60079-7	Standard for explosive atmospheres – Part 7: Equipment protection by increased safety.			
IEC 60079-11	Standard for explosive atmospheres – Part 11: Equipment protection by intrinsic safety			
IEC 60079-15	Standard for explosive atmospheres – Part 15: Equipment protection by various modes of sealing.			
IEC 60079-17	Standard for explosive atmospheres—Part 17: electrical installations inspection and maintenance			
IEC 60079-18	Standard for explosive atmospheres – Part 18: Equipment protection by encapsulation.			

AS/NZS 2381.1:2005	Standard for electrical equipment within explosive gas atmospheres—selection, installation and maintenance—general requirements			
AS/NZS 61241.10:2005	Standard for electrical apparatus for use in the presence of combustible dust—classification of areas where combustible dusts are or may be present			
AS/NZS 1020:1995 **SANS 10123**	Standard for the control of undesirable static electricity			

APPENDIX C. Survey Responses

Question 1: Please indicate your role in the company

Professional role within the business	
Role in factory	Responses
Site Engineer	**7**
Production Manager	**2**
Process / Safety Engineer	**4**
Health & Safety Representative Officer	**4**
TOTAL	**17**

Question 2: Please indicate the availability of the following processes on your site

Processing plants classifications	
Boilers	**10**
Dry silo storage	**5**
Solvent extraction	**7**
Refinery	**9**
Edible oil (by-products)	**7**
Bulk liquid storage	**7**
Total	**45**

Question 3: What is your level of awareness regarding the dust and gas explosion prevention approaches?

	NOT AT ALL AWARE–	SLIGHTLY AWARE–	SOMEWHAT FAMILIAR–	MODERATELY AWARE–	EXTREMELY AWARE–	TOTAL–
Q1: Identifying hazards and unsafe conditions presented by raw materials; chemical solvents; by-products and finished goods.	**0**	**1**	**3**	**8**	**5**	**17**
Q2: Understanding the hazards; causes and effects and how they interact with the holistic site system.	**0**	**2**	**3**	**8**	**4**	**17**
Q3: Area classification -Zoning of Areas	**3**	**1**	**4**	**4**	**5**	**17**
Q4: Hazard Elimination - Avoiding hazard	**1**	**3**	**4**	**4**	**5**	**17**
Q5: Hazard Moderation- Reducing severity	**2**	**2**	**2**	**5**	**6**	**17**
Q6: Passive Barriers - Usage of safeguards such as: vapour walls; steel structure and double door system	**0**	**4**	**2**	**7**	**4**	**17**
Q7: Active Barriers - Usage of active systems such as: Fixed detectors; mobile detectors; sprinkling system; ventilation	**1**	**4**	**3**	**5**	**4**	**17**
Q8: Standard Operating Procedures	**1**	**1**	**2**	**6**	**7**	**17**
Q9: Developing Safe Maintenance Procedures	**0**	**2**	**3**	**4**	**8**	**17**
Q10: Housekeeping Procedures	**2**	**1**	**1**	**3**	**10**	**17**
Q11: Legal Liability Compliance - Legal appointments of management personnel	**1**	**2**	**5**	**3**	**6**	**17**
Q12: Process Risk Management	**1**	**3**	**4**	**4**	**5**	**17**
Q13: Process/ Equipment Integrity (Re-certification of pressure vessels)	**3**	**4**	**5**	**1**	**4**	**17**
Q14: Code of Conduct and Disciplinary Procedures	**1**	**2**	**1**	**7**	**6**	**17**
Q15: Company standards and Regulations	**0**	**1**	**2**	**8**	**6**	**17**
Q16: Goal setting and Human Performance Monitoring	**1**	**2**	**3**	**6**	**5**	**17**
Q17: Training and Enhancing of Process Safety Knowledge	**0**	**2**	**2**	**5**	**8**	**17**

Question 4: To what extent do you utilize the dust and gas explosion prevention principles and equipment?

	NEVER USE–	ALMOST NEVER–	OCCASIONALLY/ SOMETIMES–	ALMOST EVERY TIME–	FREQUENTLY USE–	TOTAL–
Q1: Identifying hazards and unsafe conditions presented by raw materials; chemical solvents; by-products and finished goods.	1	1	7	3	5	17
Q2: Understanding the hazards; causes and effects and how they interact with the holistic site system	2	0	4	5	6	17
Q3: Area classification -Zoning of Areas	2	2	7	3	3	17
Q4: Hazard Elimination - Avoiding hazard	1	1	6	3	6	17
Q5: Hazard Moderation- Reducing severity	1	4	3	4	5	17
Q6: Passive Barriers - Usage of safeguards such as: vapour walls; steel structure and double door system	2	2	5	4	4	17
Q7: Active Barriers - Usage of active systems such as: Fixed detectors; mobile detectors; sprinkling system; ventilation	1	3	3	6	4	17
Q8: Standard Operating Procedures	1	0	3	5	8	17
Q9: Developing Safe Maintenance Procedures	0	1	3	4	9	17
Q10: Housekeeping Procedures	1	1	4	1	10	17
Q11: Legal Liability Compliance - Legal appointments of management personnel - Permit to Work	0	1	5	1	10	17
Q12: Process Risk Management	1	3	2	4	7	17
Q13: Process/ Equipment Integrity (Re-certification of pressure vessels)	4	0	5	3	5	17
Q14: Code of Conduct and Disciplinary Procedures	0	0	5	5	7	17
Q15: Company standards and Regulations	0	1	3	3	10	17
Q16: Goal setting and Human Performance Monitoring	2	2	2	7	4	17
Q17: Training and Enhancing of Process Safety Knowledge	1	1	3	4	8	17

Question 5: Please rate below standard codes & scope according to the level of consideration

	WOULD NOT CONSIDER–	MIGHT OR MIGHT NOT CONSIDER–	DEFINITELY CONSIDER–	TOTAL–
Q1: AS/NZS 4745:2004 - Standard for handling of combustible dusts	**1**	**5**	**11**	**17**
Q2: AS/NZS 3833:2007 - Standard for the storage and handling of mixed classes of dangerous goods.	**1**	**4**	**12**	**17**
Q3: NFPA 654 - Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids	**0**	**4**	**13**	**17**
Q4: SANS 10108 - Standard for the classification of hazardous locations and the selection of apparatus for use in such locations	**2**	**4**	**11**	**17**
Q5: NFPA 499 - Standard for the classification of combustible dusts and of hazardous (classified) locations for electrical installations in chemical process areas	**0**	**5**	**12**	**17**
Q6: IEC 60079-10-2 - Standard for explosive atmospheres Part 10–2: classification of areas—combustible dust atmospheres	**1**	**5**	**11**	**17**
Q7: IEC 60079-0 - Standard for explosive atmospheres—Part 0: equipment—general requirements	**0**	**9**	**8**	**17**
Q8: IEC 60079-1 - Standard for explosive atmospheres – Part 1: Equipment protection by flameproof enclosure.	**0**	**3**	**14**	**17**
Q9: IEC 60079-2 - Standard for explosive atmospheres – Part 2: Equipment protection by pressurized enclosures	**1**	**6**	**10**	**17**
Q10: IEC 60079-5 - Standard for explosive atmospheres – Part 5: Equipment protection by powder filling.	**0**	**8**	**9**	**17**
Q11: IEC 60079-6 - Standard for explosive atmospheres – Part 6: Equipment protection by oil immersion.	**1**	**8**	**8**	**17**
Q12: IEC 60079-7 - Standard for explosive atmospheres – Part 7: Equipment protection by increased safety.	**1**	**6**	**10**	**17**
Q13: IEC 60079-11 - Standard for explosive atmospheres – Part 11: Equipment protection by intrinsic safety	**2**	**3**	**12**	**17**
Q14: IEC 60079-15 - Standard for explosive atmospheres – Part 15: Equipment protection by various modes of sealing.	**0**	**8**	**9**	**17**
Q15: IEC 60079-17 - Standard for explosive atmospheres—Part 17: electrical installations inspection and maintenance	**1**	**5**	**11**	**17**
Q16: IEC 60079-18 - Standard for explosive atmospheres – Part 18: Equipment protection by encapsulation.	**1**	**7**	**9**	**17**
Q17: AS/NZS 2381.1:2005 - Standard for electrical equipment within explosive gas atmospheres—selection, installation and maintenance—general requirements	**1**	**7**	**9**	**17**
Q18: AS/NZS 61241.10:2005 - Standard for electrical apparatus for use in the presence of combustible dust—classification of areas where combustible dusts are or may be present	**1**	**8**	**8**	**17**
Q19: AS/NZS 1020:1995 /SANS 10123 - Standard for the control of undesirable static electricity	**1**	**8**	**8**	**17**